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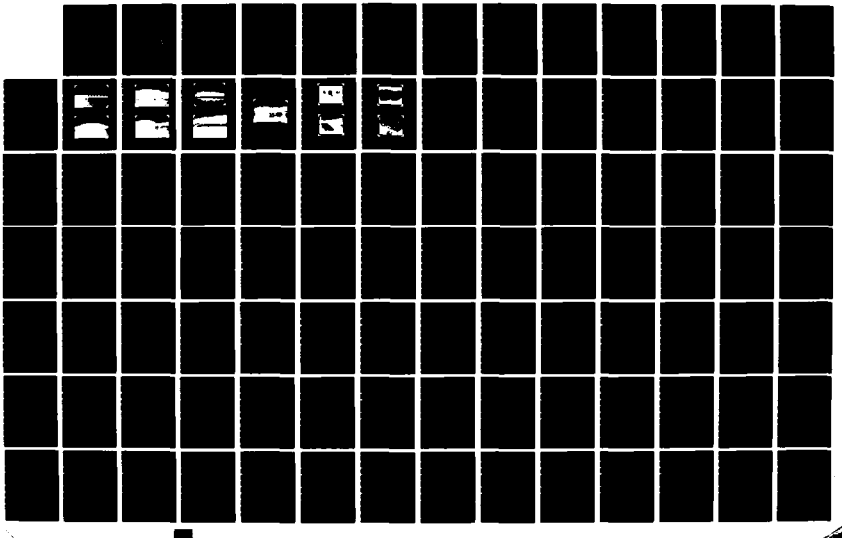

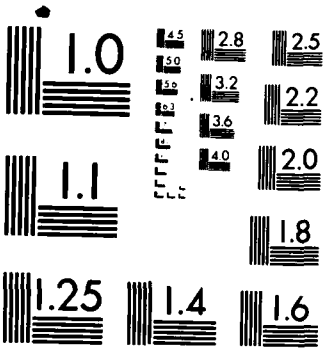

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1981 HARTWELL LAKE

WATER QUALITY STUDY

PREPARED SEPTEMBER, 1982

BY

JAMES H. CARR AND ASSOC., INC.

COLUMBIA, S. C.

FOR

U. S. ARMY CORPS OF ENGINEERS

SAVANNAH DISTRICT

SAVANNAH, GEORGIA

CONTRACT DACW 21-81-C-0068

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Herein are reported the results of a one-year detailed investigation into the existing biological, chemical, and physical characteristics of Hartwell Lake, an impoundment located in northwestern South Carolina and northeastern Georgia. The project was initiated in an attempt to develop water resource management capabilities for the reservoir. This water quality study was one of three conducted on the upper Savannah River during 1981, the others being on the existing Clarks Hill Reservoir and the pre-impoundment conditions of the proposed Richard B. Russell system.

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A series of sampling sites was chosen to allow a comprehensive evaluation of the overall system, encompassing the lake proper, the two feeder rivers, and points immediately downstream of the reservoir. The sampling regime enabled the determination of spatial (both horizontal and vertical), seasonal, and daily variations in biological and chemical parameters.

Sampling and analytical methodologies, as well as the results, are detailed. Discussions and conclusions on the overall water quality of Hartwell Lake, as well as potential problem areas, are included. All data generated are included in tabular form, and recommendations for future studies are presented. All appropriate information is to be stored in the Environmental Protection Agency's (EPA) Data Storage and Retrieval System (STORET).

Overall, Hartwell Lake is typical of large, mesotrophic reservoirs common to the southeastern portion of the United States. There are few major problems associated with the water chemistry and biology of the system, although both an apparent trend towards the decreasing of the pH in the lake and a tendency for extremely low dissolved oxygen to occur at depth during the summer should be noted. In addition, bacterial concentrations at several recreational areas occasionally exceeded recommended level and concentrations may increase with lake usage. Metals and organics (including pesticides) present no major problems typical of neighboring systems. Polychlorinated biphenyl (PCB) levels, once a serious problem in Twenty-Six Mile Creek, have declined to concentrations below those of concern.

Populations of phytoplankton, periphyton, and zooplankton are primarily seasonally dependent, but horizontal spatial trends are also evident. Benthic macroinvertebrates are also seasonally influenced, but assemblages are more dependent on sediment characteristics and hydrological conditions. All populations are generally typical of mesotrophic reservoirs and, as such, are similar to the populations of near-by systems.

This study was designed to assess the general prevailing conditions of the entire Hartwell system and as executed provides an excellent analysis of these baseline conditions.

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I ABSTRACT

Herein are reported the results of a one-year detailed investigation into the existing biological, chemical, and physical characteristics of Hartwell Lake, an impoundment located in northwestern South Carolina and northeastern Georgia. The project was initiated in an attempt to develop water resource management capabilities for the reservoir. This water quality study was one of three conducted on the upper Savannah River during 1981, the others being on the existing Clarks Hill Reservoir and the pre-impoundment conditions of the proposed Richard B. Russel system.

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Populations of phytoplankton, periphyton, and zooplankton are primarily seasonally dependent, but horizontal spatial trends are also evident. Benthic macroinvertebrates are also seasonally influenced, but assemblages are more dependent on sediment characteristics and hydrological conditions. All populations are generally typical of mesotrophic reservoirs and, as such, are similar to the populations of near-by systems.

This study was designed to assess the general prevailing conditions of the entire Hartwell system and as executed provides an excellent analysis of these baseline conditions. Due to the brief time span and the broad nature of the study, it is of limited value as a basis for predictive modelling of specific questions.

II OBJECTIVES

The purpose of this study is to provide a general assessment of the chemical and biological conditions prevalent in Hartwell Lake, its major headwaters, and its releases.

The specific objectives include:

a) the establishment of existing water quality conditions throughout the study area

b) the identification of existing water quality/environmental problems or areas most likely to develop these problems

c) the collection of data which will aid in devising water quality guidance criteria for resevoir control and discharge

d) the assessment of current heavy metal and chlorinated hydrocarbon concentrations in sediments and (food chain) organisms

e) the determination of existing bacterial concentrations at recreational areas

f) the identification of temporal and spatial variations in chemical and biological species

g) the collection of information that will provide an adequate data base and understanding of Hartwell Lake project conditions so as to facilitate coordination with state agencies to implement watershed pollution control.

III INTRODUCTION

The Hartwell Lake impoundment is located in northwestern South Carolina and northeastern Georgia on the upper Piedmont Plateau (Figure 1). The lake consists of two major branches which diverge approximately 11 kilometers (7 miles) above Hartwell Dam, and which are the inundated valleys of the Tugaloo and Seneca Rivers (Figure 2). The longest arm, the Tugaloo branch, is nearly 80 kilometers (50 miles) in length, and the drowned river bed forms the state line separating South Carolina and Georgia. The Seneca arm lies entirely within South Carolina and extends for approximately 72 kilometers (45 miles). Hartwell Dam is located 488 kilometers (305 miles) northeast of the mouth of the Savannah River.

At the top of its power pool, Hartwell Lake covers 55,950 acres and has a shoreline of 1,540 kilometers (982 miles). Flood control is an important function of the lake with storage of 293,000 acre-feet of water above its normal power pool capacity. Hartwell Lake provides hydroelectric power through four turbines located in the dam (a fifth unit is planned), recreational benefits, and a dependable water supply for the cities of Hartwell, Georgia, and Anderson, Clemson, and Pendleton, South Carolina.

The acquisition of prevailing water quality data is desirable for any body of water that supports viable fish and wildlife populations and is utilized for recreational and municipal purposes. In the case of Hartwell Lake, additional incentives for collection of this data exist. The completion of the Richard B. Russell Dam, and subsequent impoundment, will create a three-lake complex on the Savannah River. Hartwell Lake, the newly-created lake, and Clark Hill Lake will extend from the foothills of the piedmont to the coastal plain, a distance greater than 160 kilometers (100 miles).

The formation of this three-lake complex has resulted in concern as to a possible decline in the water quality of the lower two lakes, particularly in reference to the dissolved oxygen content of the water. The expressed concern is that without a flowing river system, oxygen-depleted water drawn from the depths of Hartwell Lake will not be re-aerated before entering another area of reduced circulation, the Richard B. Russell impoundment. The same conditions will prevail as Richard B. Russell water is released into Clark Hill Lake.

The present study was initiated in order to establish baseline information on the chemical and biological characteristics of the Hartwell Lake system. This investigation was performed for the U.S. Army Corps of Engineers under contract Number DACW 21-81-C-008.

FIGURE 1. Location of Hartwell Lake

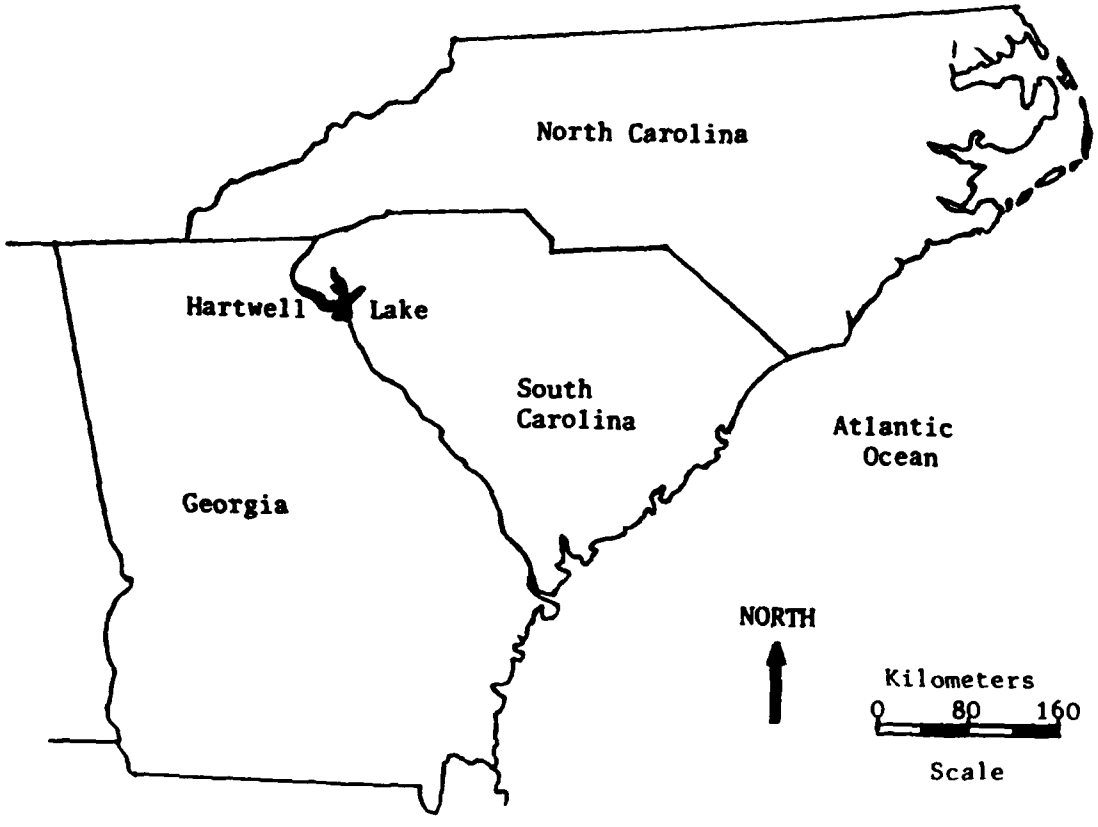
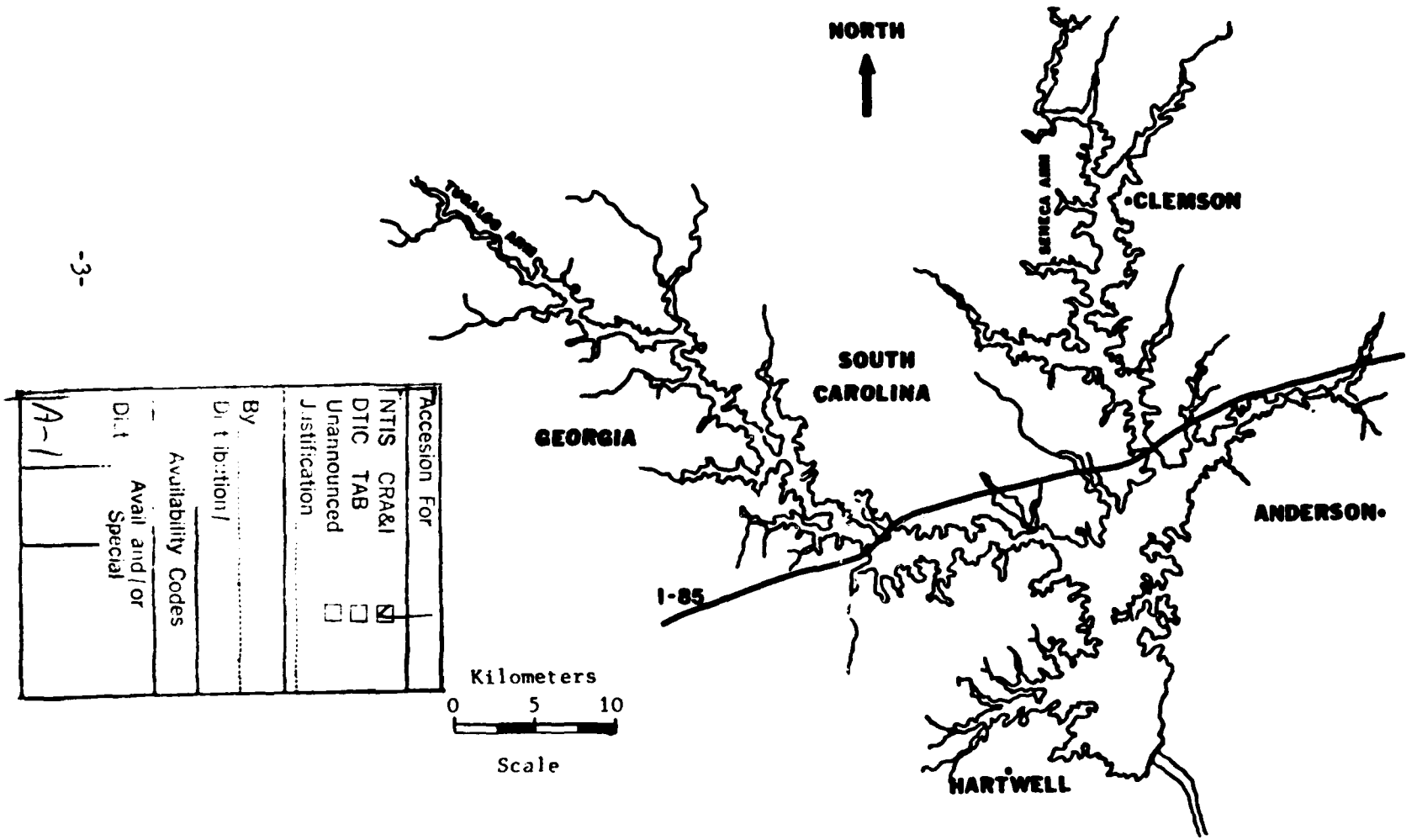


FIGURE 2

Hartwell Lake



IV METHODS AND TECHNIQUES

Site Location

The U. S. Army Corps of Engineers designated general sampling stations, and final locations were determined after on-site inspections. The approximate positions of all twenty stations are shown in Figure 3, and the exact coordinates and type of measurements conducted are given for all twenty stations in Table 1. Stations 1-8 are lake sites and all water quality parameters were recorded at these locations. The shoreline closest to all eight lake stations was heavily wooded, with hardwoods predominating.

Hartwell Lake can be divided into three sections: the main section immediately above the dam and the two arms that are the drowned valleys of the Seneca and Tugaloo Rivers. Stations 1 and 2 are in the main section of the lake and are near the dam and the divergence of the two arms, respectively. Both are the deepest stations sampled, with depths in excess of 40 meters. Station 1 is adjacent to Bouy 2 and the approximate location relative to Hartwell Dam can be seen in figure 4. Station 2 is located at Bouy S-24 (figure 5). Stations 3, 4, and 5 are located in the Seneca arm of the lake. Stations 3 (figure 6) and 4 (figure 7) are intermediate in depth ($\simeq$30 meters) and are adjacent to Bouys S-28 and S-37, respectively. Station 5 (figure 8) is in a small cove immediately south of Martin's Creek, opposite Bouy S-67, and is shallow ($\leq$10 meters). Stations 6 and 7 are also intermediate in depth and are in the Tugaloo arm of Hartwell Lake. Stations 6 (figure 9) and 7 (figure 10) are located near Bouys T-12A and T-67, respectively. Station 8 is an extremely shallow site located in Twenty Six Mile Creek (approximately six kilometers from the main lake) and is not pictured.

Stations 9 (figure 11) and 10 (figure 12) are river stations on the Seneca and Tugaloo, respectively. Station 9 actually had samples taken at three different locations; the water quality was taken at the first position listed in Table 1, while the benthic sampling was originally conducted approximately one kilometer below this (the second position in Table 1.), and then was moved an additional two kilometers further downstream (the third position in Table 1). The water sampling was conducted at the South Carolina Highway 183 crossing. Station 10 was located at the South Carolina Highway 184 crossing.

Stations 11 (figure 13) and 12 (figure 14) are on the Savannah River and are approximately one and three kilometers, respectively, below Hartwell Dam. Station 11 was located at the U. S. Highway 29 crossing while the water sampling at Station 12 was conducted at the Georgia Highway 181 crossing (the first position given in Table 1). Benthic sampling was conducted approximately 200 meters below this site (the second position listed in Table 1).

FIGURE 3

General Station Locations

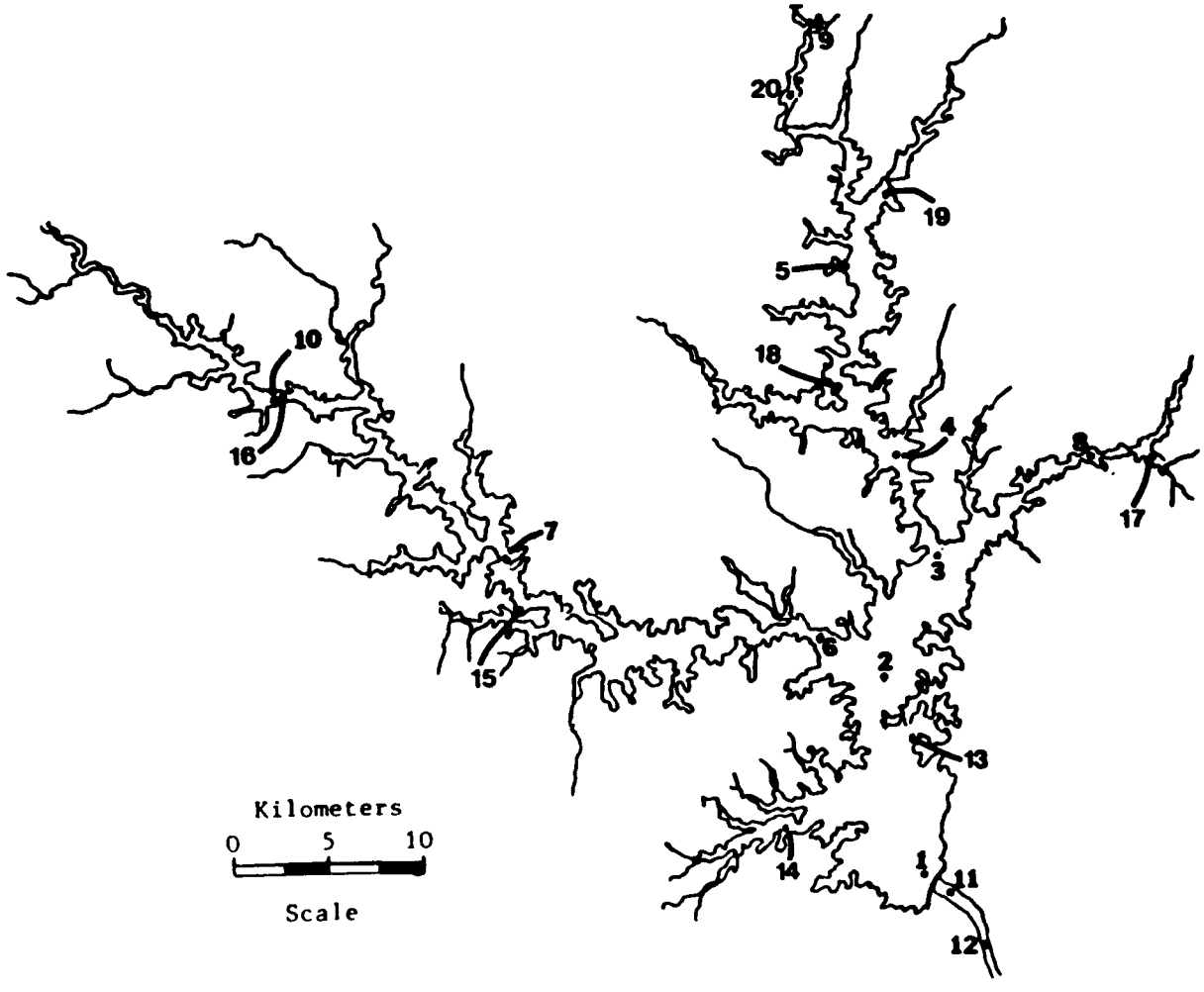


TABLE 1

Station Description and Location

Station #	Type	Description	Latitude	Longitude
1	Lake	Mid-Channel	34° 21' 32"	82° 49' 22"
		Shallow	34° 21' 37"	82° 49' 15"
2	Lake	Mid-Channel	34° 26' 18"	82° 51' 20"
3	Lake	Mid-Channel	34° 31' 37"	82° 48' 50"
		Shallow	34° 31' 38"	82° 48' 46"
4	Lake	Mid-Channel	34° 32' 57"	82° 49' 44"
5	Lake	Mid-Channel	34° 37' 27"	82° 52' 30"
		Shallow	34° 37' 29"	82° 52' 28"
6	Lake	Mid-Channel	34° 28' 53"	82° 53' 32"
7	Lake	Mid-Channel	34° 31' 37"	83° 04' 43"
		Shallow	34° 31' 39"	83° 04' 32"
8	Lake	Mid-Channel	34° 33' 59"	82° 42' 55"
9	River	Mid-Channel	34° 47' 29"	82° 53' 00"
		*	34° 45' 51"	82° 53' 38"
		*	34° 46' 11"	82° 53' 10"
10	River	Mid-Channel	34° 38' 0' '	83° 16' 58"
11	River	Mid-Channel	34° 21' 08"	82° 48' 47"
12	River	Mid-Channel	34° 19' 22"	82° 47' 17"
		*	34° 19' 26"	82° 47' 18"
13	Lake	Bacteriological	34° 25' 41"	82° 49' 20"
14	Lake	Bacteriological	34° 23' 00"	82° 54' 38"
15	Lake	Bacteriological	34° 29' 55"	83° 04' 29"
16	Lake	Bacteriological	34° 36' 32"	83° 13' 20"
17	Lake	Bacteriological	34° 34' 43"	82° 40' 27"
18	Lake	Bacteriological	34° 35' 45"	82° 52' 03"
19	Lake	Bacteriological	34° 42' 19"	82° 50' 16"
20	Lake	Bacteriological	34° 45' 51"	82° 53' 38"

*Explained in text.

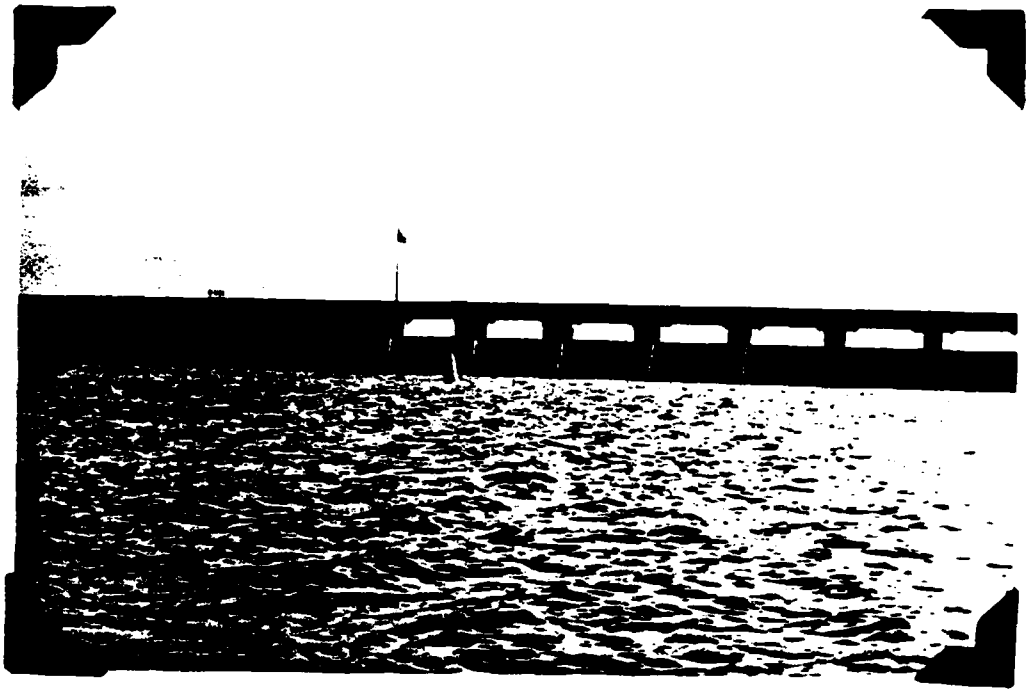


Figure 4. Station 1

Figure 5. Station 2

Figure 6. Station 3

Figure 7. Station 4

Figure 8. Station 5

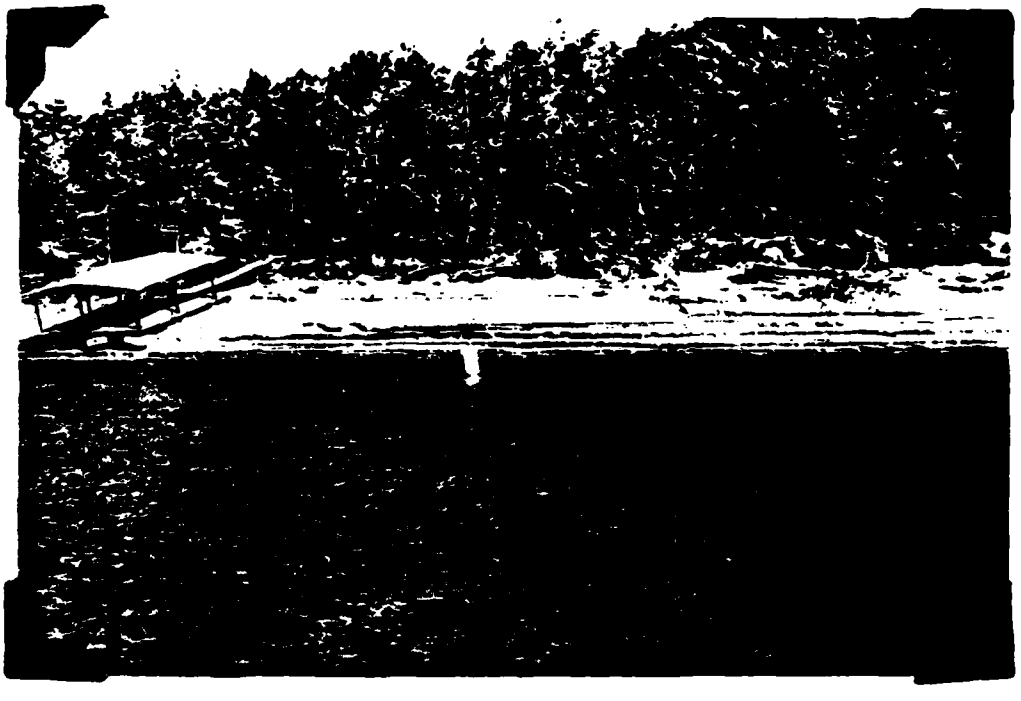


Figure 9. Station 6

Figure 10. Station 7

Figure 11. Station 9

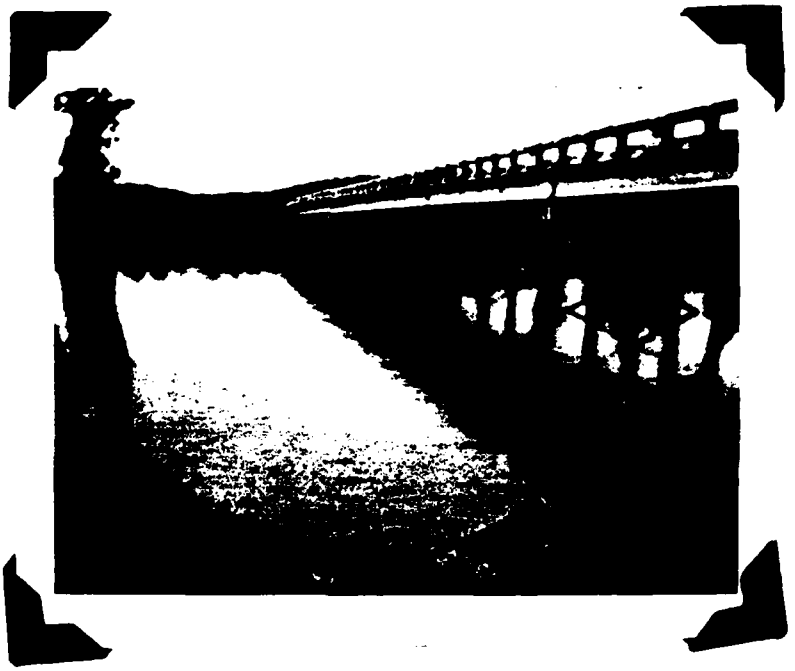


Figure 12. Station 10

Figure 13. Station 11

Figure 14. Station 12

All river stations had shorelines that were heavily wooded with primarily hardwoods. Stations 9, 11, and 12 were subject to high current velocities during periods of power generation, while Station 10 experienced much slower currents.

All data generated will be entered in the Environmental Protection Agency's (EPA) data Storage and Retrieval (STORET) system.. Table 2 details STORET codes for all sampling methodologies and their respective analytical techniques for all measured values recorded throughout this study. In addition, the same table contains maximum allowable sample holding times, preservation techniques, detection limits, and sample containers.

Sampling Schedule

To define seasonal trends in the various parameters, sampling was conducted throughout the year. Water quality analyses were performed during February, June, August, and November. Phytoplankton, zooplankton, macrobenthic invertebrates, and tissue and sediment analyses were also sampled throughout the year, but during various months. Exact dates are given in the appropriate sections and in Table 3.

Diel Study

Each of the eight lake stations was extensively profiled over a twenty-four hour period to determine diel variations in water quality. One station was sampled per day, with duplicate vertical profiles taken every three hours for temperature, D.O., pH, and conductivity. Depth-integrated composite samples were also collected every three hours for the determination of total residue, nutrients, CO_2, alkalinity, TOC, BOD, and COD. This sampling effort was conducted during the summer (July 31-Aug. 8) when the lake was stratified, and in addition to the composites, samples were collected at the surface, above and below the thermocline, and at the bottom.

In Situ Measurements

Six parameters dissolved oxygen (D.O.), temperature, pH, specific conductivity, oxidation-reduction potential (ORP), and % light transmission were vertically profiled for the eight lake stations. To determine the extent of stratification, a minimum of 10 values was obtained for each measurement from 0.3, 2, 4, 6, 8, and 10 meters, and then four additional readings equally spaced between 10 meters and the bottom, although additional values were often obtained for each measurement. These six parameters were recorded in situ, and all water quality tests, excluding percent light transmission, were run in duplicate unless otherwise noted.

Dissolved oxygen was measured with a YSI Dissolved Oxygen Meter (Model 54) utilizing a membrane electrode. The D.O. meter was calibra-

TABLE 2

Parameter STORET Codes and Various Characteristics

Storet Code	Parameter	Analytical Methodology	Units	Holding Time	Preservation Technique	Container	Detection Limit
			PHYSICAL DATA				
00074	Depth of 1% surface light	Li-Cor Submersible Quantum Meter (Li-185B)	m	None	(in situ)	--	--
00010	Water Temperature	YSI DO Meter (51B)	°C	None	(in situ)	--	--
00095	Conductivity	YSI SCT Meter (33)	umho/cm @ 25° C	None	(in situ)	--	--
00090	ORP	Orion 407A Specific Ion Meter	mv	None	(in situ)	--	--
00299	DO	YSI DO Meter (51B)	mg/l	None	(in situ)	--	--
00403	pH	Orion 407A Specific Ion Meter	std. units	None	(in situ)	--	--
00080	Color	# 6 *	Pt-Co units	24 hours	4°C	P	--
00070	Turbidity	# 6	JTU	1 week	4°C	P	--
00515	Total Filterable Residue	# 2 *	mg/l	1 week	4°C	P	10
00530	Total Nonfilterable Residue	# 2	mg/l	1 week	4°C	P	10
			CHEMICAL DATA				
00410	Total Alkalinity	# 2 *	mg$CaCo_3$/l	24 hours	4°C	P	--
00940	Chloride	# 2	mgCl/l	1 week	None	P	1
00945	Dissolved sulfate	# 2	mgSO_4/l	1 week	4°C	P	1
00747	Total Sulfide	# 2	mgS/l	24 hours	2ml Zn acetate/l	P	0.1
00916	Calcium	# 6 *	mgCa/l	6 mo	HNO_3 to pH< 2	P	0.1
00900	Hardness	Calculated	mg$CaCo_3$/l	--	--	--	--
01047	Iron II	# 6 *	mgFe/l	6 mo	HNO_3 to pH < 2	P	0.05
01045	Total Iron	# 6	mgFe/l	6 mo	HNO_3 to pH < 2	P	0.05
00927	Total Magnesium	# 6	mgMg/l	6 mo	HNO_3 to pH < 2	P	0.1
01056	Dissolved Manganese	# 6	mgMn/l	6 mo	HNO_3 to pH < 2	P	0.05
01055	Total Manganese	# 6	mgMn/l	6 mo	HNO_3 to pH < 2	P	0.05
00937	Potassium	# 6	mgK/l	6 mo	HNO_3 to pH < 2	P	0.1
00929	Sodium	# 6	mgNa/l	6 mo	HNO_3 to pH < 2	P	0.01
00680	TOC	# 6	mgC/l	24 hours	4°C; H_2SO_4 to pH < 2	P	1

TABLE 2

Parameter STORET Codes and Various Characteristics

Storet Code	Parameter	Analytical Methodology	Units	Holding Time	Preservation Technique	Container	Detection Limit
00405	CO_2	Calculated	mg/l	--	--	--	--
00610	Total Ammonia	# 6 *	mgN/l	24 hours	4°C; H_2SO_4 to pH< 2	P	0.01
00630	Nitrate and Nitrite	# 2	mgN/l	"	"	P	"
00625	TKN	# 6	mgN/l	1 week	"	P	0.1
70507	Dissolved Orthophosphate	# 6	mgP/l	24 hours	4°C	P	0.01
00655	Total Phosphorus	# 6	mgP/l	1 week	4°C; H_2SO_4 to pH<2	P	"
00310	BOD		mg/l			G	
00340	COD		mg/l			G	
31616	Fecal Coliform	# 2 *	MPN/100 ml	12 hours	4°C	Sterilized	--

SEDIMENTS

	Grain Size	(See Text) **	--	--	(See Text) **	G	--
	% Total Solids	# 1 *	% Total dry weight	2 weeks	4°C	G	--
	% Volatile Solids	# 1	% Total dry weight	2 weeks	4°C	G	--
00687	TOC		gC/kg drywt	"	" ; H_2SO_4	P	2
00627	TKN	# 1	mgN/kgdrywt	"	"	P	1
00557	Oil and Grease	# 5 *	mg/kg drywt	"	"	P	50
00668	Total Phosphorus	# 13 *	mgP/kgdrywt	"	"	P	0.5
01003	Arsenic	# 13	mgAs/kg drywt	3 months	HNO_3	P	0.1
01028	Cadmium	# 13	mgCd/kg drywt	"	"	P	1
01029	Chromium	# 13	mgCr/kg drywt	"	"	P	"
01043	Copper	#13	mgCu/kg drywt	"	"	P	"
01170	Iron	# 13	mgFe/kg drywt	"	"	P	"
01052	Lead	# 13	mgPb/kg drywt	"	"	P	"
01053	Manganese	# 13	mgMn/kg drywt	"	"	P	"
71921	Mercury	#13	mgHg/kg drywt	"	"	P	"
01068	Nickel	#13	mgNi/kg drywt	"	"	P	"
01093	Zinc	# 13	mgZn/kg drywt	"	"	P	"

TABLE 2

Parameter STORET Codes and Various Characteristics

Storet Code	Parameter	Analytical Methodology	Units	Holding Time	Preservation Technique	Container	Detection Limit
	Chlorinated Hydrocarbons						
39333	Aldrin	# 7 *	ug/kg dry wt	3 months	Freeze	G	0.1
39519	PCB	# 7	"	"	"	G	"
	Lindane	# 7	"	"	"	G	"
39351	Chlordane	# 7	"	"	"	G	"
39378	Total DDT	# 7	"	"	"	G	"
39383	Dieldrin	# 7	"	"	"	G	"
39393	Endrin	# 7	"	"	"	G	"
39413	Heptachlor	# 7	"	"	"	G	"
39758	Mirex	# 7	"	"	"	G	"
39403	Toxaphene	# 7	"	"	"	G	0.5

TISSUE ANALYSIS

	Metals						
01004	Arsenic	# 8 *	mgAs/kg wet wt	3 months	Freeze	P	0.1
71960	Cadmium	# 8	mgCd/kg "	"	"	P	0.05
71939	Chromium	# 8	mgCr/kg "	"	"	P	0.1
71936	Lead	# 8	mgPb/kg "	"	"	P	"
71930	Mercury	# 8	mg^{Hg}/kg "	"	"	P	0.005
01149	Selenium	# 8	mg^{Se}/kg "	"	"	P	0.1
71938	Zinc	# 8	mgZn/kg "	"	"	P	1
	Chlorinated Hydrocarbons						
39519	PCB	# 14 *	ug/kg wet wt	3 months	Freeze	G	0.1
39075	Lindane	# 14	" "	"	"	G	"
39349	Chlordane	# 14	" "	"	"	G	"
39318	DDD	# 14	" "	"	"	G	0.5
39332	DDE	# 14	" "	"	"	G	"
39378	DDT	# 14	" "	"	"	G	"
39387	Dieldrin	# 14	" "	"	"	G	0.1
39414	Heptachlor	# 14	" "	"	"	G	1
39758	Mirex	# 14	" "	"	"	G	5
39403	Toxaphene	# 14	" "	"	"	G	5

TABLE 2

Parameter STORET Codes and Various Characteristics

Storet Code	Parameter	Analytical Methodology	Units	Holding Time	Technique	Container	Limit
			PHYTOPLANKTON				
71300	Chlorophyta	(See Text)**	#/ml	None	(See Text)**	P	--
71432	Cyanophyta	"	"	"	"	P	"
71469	Cryptophyta	"	"	"	"	P	"
71393	Chrysophyta	"	"	"	"	P	"
71400	Bacillariophyta	"	"	"	"	P	"
71381	Pyrrophyta	"	"	"	"	P	"
71377	Euglenophyta	"	"	"	"	P	"
			ZOOPLANKTON				
46502	Total Count/liter	"	"	None	(See Text)**	P	--
71270	Rotifera	"	"	"	"	P	"
71291	Cladocera	"	"	"	"	P	"
71297	Copepoda	"	"	"	"	P	"
71287	Arthropoda	"	"	"	"	P	"
71295	Ostracoda	"	"	"	"	P	"
			PERIPHYTON				
71673	Chlorophyta	"	"	None	(See Text)**	P	--
71674	Cryptophyta	"	"	"	"	P	"
71675	Cyanophyta	"	"	"	"	P	"
71676	Chrysophyceae	"	"	"	"	P	"
71677	Euglenophyta	"	"	"	"	P	"
71678	Pyrrophyta	"	"	"	"	P	"
70965	Periphyton Total cells per mm^2			"	"	P	"

TABLE 2

Parameter STORET Codes and Various Characteristics

Storet* Code	Parameter	Analytical Methodology	Units	Holding Time	Preservation Technique	Container	Detection Limit
	BENTHIC MACROINVERTEBRATES						
	Natural Substrates						
71484	Annelida	"	#/m^2	None	(See Text) **	P	--
71485	Mollusca	"	"	"	"	P	"
71486	Platyhelminthes	"	"	"	"	P	"
71487	Arthropoda	"	"	"	"	P	"
71488	Total Benthic Macroinvertebrates	"	"	"	"	P	"
	Artificial Substrates						
71489	Annelida	(See Text) **	#/m^2	None	(See Text) **	P	--
71490	Mollusca	"	"	"	"	P	"
71491	Corbitula	"	"	"	"	P	"
71492	Platyhelminthes	"	"	"	"	P	"
71493	Arthropoda	"	"	"	"	P	"
71495	Total Drift Macroinvertebrates	"	"	"	"	P	"
71496	Drift Macroinvertebrates Biomass	"	g/m^2	"	"	P	"
71497	Diversity Index, Shannon-Wiener, Drift Invertebrates	"	#/sample	"	"	P	"

* Number refers to reference (in Literature Cited - Water Quality Section) from which methodologies and techniques were obtained

** See appropriate Methodology section for techniques utilized

TABLE 3

Sample Collections and Dates Listed by Station

Collection	Date (1981)
Station 6	
Water Quality	2/8 6/6 8/3-4 11/4
Phytoplankton	2/8 4/4 6/6 8/2 11/1
Zooplankton	2/21 4/4 6/6 8/2 11/1
Sediments	March September
Station 7	
Water Quality	2/5 6/5 8/1-2 11/3
Phytoplankton	2/5 4/4 6/5 8/1 11/1
Periphyton*	March June November
Zooplankton	2/21 4/4 6/5 8/1 11/1
Macrobenthic Invertebrates	
PONAR	4/4 6/5 11/1
Hester-Dendy*	April June November
Sediments and Tissues	March September
Station 8	
Water Quality	2/5 6/7 8/5-6 11/4
Phytoplankton	2/7 4/5 6/7 8/3 10/30
Zooplankton	2/21 4/5 6/7 8/3 10/30
Sediments and Tissues	March September
Station 9	
Water Quality	2/8 6/7 8/8 11/4
Bacteria	2/8 8/8 11/4
Periphyton	March June November
Macrobenthic Invertebrates	
PONAR	4/4 6/7 11/4
Hester-Dendy*	April June November
Sediments and Tissues	March September
Station 10	
Water Quality	2/8 6/7 8/8 11/4
Bacteria	2/8 8/8 11/4
Sediments	March September
Station 11	
Water Quality	2/8 6/7 8/8 11/4
Bacteria	2/8 8/8 11/4
Sediments	March
Station 12	
Water Quality	2/8 6/7 8/8 11/4
Bacteria	2/8 8/8 11/4
Periphyton	March June November

TABLE 3

Sample Collections and Dates Listed by Station

Collection	Date (1981)
Station 1	
Water Quality	2/12 6/6 8/6-7 11/2
Phytoplankton	2/12 4/4 6/6 8/6 11/1
Periphyton*	March June November
Zooplankton	2/21 4/4 6/7 8/6 11/1
Macrobenthic Invertebrates	
PONAR	4/4 6/6 11/1
Hester-Dendy*	April June November
Sediments	March September
Station 2	
Water Quality	2/8 6/6 8/7-8 11/3
Phytoplankton	2/8 4/4 6/6 8/7 11/1
Zooplankton	2/21 4/4 6/7 8/7 11/1
Sediments and Tissues	March September
Station 3	
Water Quality	2/6 6/7 7/30-31 11/4
Phytoplankton	2/12 4/5 6/7 7/30 11/1
Periphyton	March June November
Zooplankton	2/21 4/5 6/6 7/30 11/1
Macrobenthic Invertebrates	
PONAR	4/5 6/7 11/4
Hester-Dendy*	April June November
Sediments	March September
Station 4	
Water Quality	2/7 6/7 8/4-5 11/4
Phytoplankton	2/7 4/5 6/7 8/4 11/1
Zooplankton	2/21 4/5 6/6 8/5 11/1
Sediments and Tissues	March September
Station 5	
Water Quality	2/7 6/6 8/2-3 11/4
Phytoplankton	2/7 4/5 6/6 8/5 11/1
Periphyton*	March June November
Zooplankton	2/21 4/5 6/6 8/5 11/1
Macrobenthic Invertebrates	
PONAR	4/5 6/6 11/4
Hester-Dendy*	April June November
Sediments	March September

TABLE 3

Sample Collections and Dates Listed by Station

Collection	Date (1981)
Station 12 (Continued)	
Macrobenthic Invertebrates	
PONAR	4/4 6/7 11/4
Hester-Dendy*	April June November
Sediments and Tissues	March September
Stations 13-20	
Bacteria	2/8 8/8 11/4

ted daily against a sample titrated by the standard Winkler Method for D.O.. Temperature was measured using the thermistor on the same instrument and was checked daily against an analytical thermometer. Conductivity was determined using a YSI Model 31 instrument. ORP and pH values were measured on an Orion (Model 404) Specific Ion Meter, and the instrument was calibrated twice daily against standard buffers of pH 4.0, 7.0, and 10.0. Light transmission was profiled with a submersible quantum sensor (Li-cor model Li-185B) by taking light measurements at the surface, subsurface (0.3 meters), and every meter down to the one percent level.

Water Quality Sampling and Analysis

Dissolved sulfide, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) samples were collected one meter above the bottom at Stations 1-8. The remaining physical-chemical values for both lake and river stations were determined on a composite sample representative of the water column, consisting of one liter subsamples from all measured depths. All water samples, excluding bacteria, were collected by a 1.8 liter PVC Beta Bottle sampler. Duplicate water samples for all analyses were obtained from two separate casts rather than by subsampling one volume.

Containers for all samples were pre-cleaned in the laboratory, acid rinsed when necessary, and sealed for transport into the field following EPA-approved procedures. Collected samples were either kept packed in ice (4° C) or frozen on dry ice. The priority of laboratory analysis for water samples was BOD, ammonia, TKN, nitrate, phosphorus, fecal coliforms, COD, TOC, chlorophyll, sulfate, metals, organics, etc., unless otherwise noted.

The determination of metals in water was accomplished by acidifying the sample with nitric acid to a pH of 2 at the time of collection. 100 milliliters of unfiltered sample is transferred to a 250 ml Griffin Beaker and 3 ml of concentrated nitric acid is added. The sample is concentrated over heat (short of boiling), cooled, and another 3 ml of concentrated nitric acid is added. The sample is gently refluxed until digestion is complete. The sample is filtered to remove silicates and other insoluble material, the volume adjusted to predetermined levels, and then analyzed on an Instrumentation Laboratory AA/AE Spectrophotometer (Model 651).

Quality Control

A check on the precision and accuracy of sample methodology and analytical techniques was performed utilizing four procedures, as follows: 1) at least 10% of all samples recorded during this study were analyzed in duplicate. 2) 10% of the appropriate samples were spiked with known concentrations to allow for recovery checks. 3) EPA and NBS certified standards were regularly used as a check on the instrumentation. 4) organic hydrocarbon standards from a local (university affiliated) pesticide analytical laboratory were utilized as standard checks, and for spike recovery.

Reagent blanks were run with each set of samples and on each new set of reagents. Blanks and standards were carried through all procedures that involved distillations, extractions, or pre-treatments, and were analyzed to verify that acceptable recovery was obtainable.

All duplicate or spike values for any parameter (water quality or biological) are included, with the sample values, in the appropriate tables or appendices, and are usually denoted by parameters. With one exception, deviations or problems encountered are discussed under the appropriate sections. Selenium presented a unique problem in that sample spikes of tissues were always below the detection limit. Spikes directly placed into clean glassware (no sample) gave acceptable recoveries. To date, attempts to explain this discrepancy have failed.

All major instrumentation was serviced and cleaned on a regular basis. Most smaller instruments (ovens, water baths, incubators, etc.) were checked on a daily basis. Most instruments were calibrated prior to each use and the ones not requiring this were calibrated on a periodic basis. Instruments that developed problems were immediately serviced.

All glassware was washed with bio-degradable detergent, rinsed at least three times with tap water, and three more times with deionized water. Glassware was acid-rinsed when applicable. Volumetric items were discarded if chipped or broken.

Bacteriology

Bacterial samples were collected in duplicate sterile disposable 0.5 liter containers from a depth of 0.3 meters below the surface and within 2 meters of the shoreline. Fecal coliform determinations were made utilizing the 15 tube Most Probable Number (MPN) method (Table 2). Initial incubation was in lauryl sulfate broth and confirmation utilized incubation at 44.5° C on EC medium. Controls included incubation of negative controls and innoculation of live organisms.

Phytoplankton and Periphyton

Although phycological research in South Carolina was begun over a century ago (Bailey 1851; Ravenell 1882), compared to most other states, our knowledge of the freshwater algae of South Carolina is very limited (Goldstein and Manzi 1976). Lake Hartwell was formed in 1961 following the construction of Hartwell Dam. Since then, despite extensive public and private usage, few biological studies on the lake have been published. This is particularly true for the algae. Kerr et al. (1970) studied the regulation of heterotrophic and autotrophic algal populations in the lake by the interaction of inorganic carbon and phosphorous concentrations.

Hern et al. (1977) presented a list of phytoplankton from three composite samples taken over three seasons in 1973 at a single station near Hartwell dam. It is understood that other studies on the algae of Lake Hartwell have been completed or are continuing by federal and state agencies. However, except for a species list, prepared in 1980 and supplied by the Corps of Engineers, none of these data has been made available for this report.

The purpose of this current investigation was to describe temporal and spatial variations in populations of phytoplankton and periphyton in Lake Hartwell, South Carolina and its major tributaries and to determine any current or potential problems that might affect responsible management decisions by appropriate public officials and agencies.

Phytoplankton

Chlorophyll a

Replicate water samples were collected in February, April, June, August and November at each lake station in 1.8 liter Beta bottles at meter intervals throughout the euphotic zone to the compensation depth. The compensation depth was assumed to be that depth which received 1% of the surface insolation as measured with a Licor submersible, spherical quantum sensor. Duplicate depth-integrated composite samples were prepared by combining equal volumes from each bottle into a single sample. Replicate 10-40 ml subsamples of each composite samples were filtered through 25 mm Gelman A/E glass fiber filters (pore size approximates 0.3 micrometers) within four hours of collection and frozen in dry ice for 24-48 hours. Chlorophyll a and phaeopigments were extracted in 90% acetone for 48 hrs in the dark at 4°C (Glover and Morris, 1979) and measured in a Turner 111-R flourometer (Yentsch and Menzel, 1963). The flourometer was calibrated with chlorophyll a standards obtained from the U. S. E. P. A.

Cell Counts

Approximately 130 ml of each composited sample described above was preserved with 0.4% glutaraldehyde and dilute rose-bengal solution. Five to ten ml subsamples were settled in sedimentation chambers and enumerated using a Nikon MS inverted microscope (Utermohl, 1936). From 250 to 760 cells were counted in each sample and converted to concentration according to the following formula:

$$\text{Cells per liter} = \frac{\text{No. cells counted}}{\text{Volume settled (ml)}} \times \frac{\text{Area of counting chamber}}{\text{Area of chamber counted}} \times \frac{1000 \text{ ml}}{1 \text{ liter}}$$

Enumerations were made in duplicate from at least two composite samples at each sampling time. Some samples were sent to Clemson University for independent analysis. Remaining samples are stored as prescribed by the U.S. Army Corps of Engineers.

Species Composition

All taxa were identified to species or variety where possible using standard algal taxonomic literature (See References). Where identification to species was impossible or impractical because of small size or inadequate preservation, taxa were enumerated by genus or lumped by category (e.g. flagellates and monads, zygotes and cysts, etc.). Species diversity was not calculated for each sample because of the necessity of lumping several taxa in the enumerations, the result of which would be to compute meaningless diversity indices.

Periphyton

Sampling

Duplicate eight-slide diatometers (Design Alliance Corporation) were mounted on the top of cement blocks and, using SCUBA, placed in 1-3 meters depth at stations 1, 3, 5, 7, 9 and 12 in February, June and October. Diatometers were recovered by SCUBA after four weeks. Slides were removed from each diatometer and preserved in 0.5% glutaraldehyde and dilute rose bengal. In February samples, at stations where periphyton growth was sparse, one side of each slide was scraped clean and a 22 x 22 mm, No 1½ coverslip was placed over the remaining side to make a wet mount. Cells were enumerated in consecutive fields measuring 22 x 0.117 mm until 200-500 cells were counted. All other samples were prepared by scraping from ½-2 slides into 100 or 1000 ml water, then drawing 5-10 ml subsamples that were added to Utermohl sedimentation chambers as described in the phytoplankton section. It was necessary to mix samples collected in June and October for 25 seconds in a blender to disperse cells from accumulated sediments and to prevent clumping while settling. From 275 to 1000 cells were counted in each sample. Duplicate and sometimes triplicate counts were made from each station at each date using the inverted microscope as described above.

Species Composition

Cells were identified to species and variety where practical, though as with the phytoplankton, some taxa were only identified to genus or lumped by category. Permanent, cleaned mounts of each sample were prepared for critical examination with phase-contrast optics for the identification of certain species.

Zooplankton

Zooplankton samples were collected from stations 1 through 8 at six to eight week intervals from February through October, 1981. However, station 3 was not sampled in October. Two samples were collected from each station per trip, using a 0.5 m diameter 80 μm mesh net. Each sample consisted of an oblique tow from the surface to maximum sample depth and back to the surface. Tows at deep stations reached depths of 20-30 m while at shallower stations the tows approached the bottom. Submerged trees prevented towing at greater depths at the deep stations. A calibrated flow meter was mounted in the mouth of the net so that the actual volume of water passing through the net could be estimated. A tow usually sampled 1-3 m^3 of water. All samples were preserved with sucrose and formalin to prevent distortion of cladocerans (Haney and Hall 1973), and stained with rose bengal so that relatively transparent species could be counted.

The relative abundance of species varied widely within samples, so each sample was counted by two methods. First, each sample was gently stirred, and a subsample of 3-10 ml (usually 5) was removed and washed onto a grid. Large organisms and relatively rare smaller organisms were then counted. A total of 2-5 subsamples were counted by this method, constituting roughly 3-6% of each sample. Very small organisms (e.g. rotifers) and relatively abundant larger ones were counted using a 1.0 ml Sedgewick-Rafter Cell. A total of 2-4 cells were counted for each sample.

Where possible, animals were identified to species. Many rotifers could only be identified to genus and some could not be identified at all due to distortion caused by the preservation technique. Unidentified forms were generally a small fraction of the total plankton in a sample. Adult copepods were identified to species but copepodids and nauplii were not. They were counted as nauplii or as calanoid copepodids or cyclopoid copepodids. In February, calanoid adults and copepodids were pooled.

Benthic Macroinvertebrates

Field Technology

Samples for the determination of benthic macroinvertebrate densities and biomass were collected by two methods. A 0.05 m^2 epoxy coated PONAR dredge was used to collect samples of the benthos in the littoral zone at mid-depth corresponding to the 1% light level, and at deep-depth well below the 1% light level. (The methodology for river and lake stations is similar to that previously described in the sediment section). Collected samples were washed immediately through a U.S. standard No. 30 sieve and preserved in 10% formalin.

The second method sampled drift macroinvertebrates using artificial substrate. Three Hester-Dendy samplers, constructed of 8 parallel plates (8 cm x 8 cm) of fiber board and having a total surface area = 0.102 m^2, were emplaced approximately 0.5 m apart at each of the three depths described above. After four weeks of exposure, the benthic samplers were sealed in plastic by divers while still in place, returned to the surface and preserved in tact with 10% buffered formalin. Samples were returned to the laboratory for picking, identification and enumeration.

Macrobenthic Invertebrates

Natural substrates - In the laboratory samples were placed in a shallow metal pan. The pan was filled with water, gently swirled, and the water decanted over a U.S. Standard No. 30 sieve. This procedure was repeated a minimum of ten times to wash all animals free of the sediment. Periodic checks of the residual sediment fraction confirmed that all animals, including attached sessile forms, were removed by this method.

The contents of the sieve were transfered to a jar and stored in 10% buffered formalin with .05% rose bengal stain. After at least 48 hrs. in the stain, the samples were gently sieved over a U.S. Standard No. 30 sieve to remove excess formalin and rose bengal. The contents of the sieve were then washed into a white enamel pan. All organisms were removed and placed into 1% buffered formalin. From each pan 2 randomly located subsamples (approximately 20% of the total sample) were removed and examined under a dissecting microscope to check for organisms missed with the unaided eye.

Identification of specimens was carried out using a Wild M5 dissecting microscope and an AO compound microscope. Standard taxonomic keys (Beck 1976; Brinkhurst 1964,1976; Brinkhurst and Jamieson 1971; Curry 1958; Edmonds et al. 1976; Mason 1973; Pennak 1978; Roback 1969; Wiggins 1977) were used for identification of organisms.

Biomass measurements were made by selecting one or more individuals of a taxon, depending upon size and availability, blotting briefly on a Kimwipe™, and weighing to the nearest .01 mg on a Perkin-Elmer Analytical balance. When possible, large numbers of individuals were used and selections were made at random in order to insure a representative range of sizes. For instance, 70 individuals of various sizes of Chaoborus sp. were weighed to obtain a mean weight of 0.53 mg/animal.

The Shannon Diversity Index was calculated as:

$$H' = p_i \log_e p_i$$

for each station (MacArthur and MacArthur, 1961.).

Artificial Substrates - In the laboratory plates were separated and washed over a U.S. Standard No. 30 sieve. Inspection of washed plates under a dissecting microscope confirmed that all animals were removed by the washing technique. The contents of the sieve were transfered to jars and

stored in 10% formalin with rose bengal. Samples were allowed to remain at least 48 hrs. in the stain before they were gently sieved over the same size mesh to remove excess formalin and stain. The samples were then placed in a white enamel pan and organisms picked in the same fashion described above, including the microscope checks for small animals. Biomass measures were obtained in the manner described above. All numbers were converted to values per m^2 and the Shannon Diversity Index was calculated as described earlier.

Sediment Analysis

Lake station sediment samples consisted of multiple grabs with an epoxy-coated PONAR™ Dredge (standard size, 0.05 m^2). The total number of grabs was composited, but due to the rocky nature of the bottom at some locations, the number of grabs necessary to obtain a representative sample varied. River sediment samples consisted of grabs transecting the river, but the problem of gravelly bottoms was compounded. Sediment analyses performed and methods used are listed in Table 2. Grain size analysis was performed using a modification of Standard Method's Particle Size Analysis of Soils (ASTM D-422). Soil samples of 200 grams were air-dried, aggregations gently broken up, and then dry-seived. An automated mechanical shaker and a set of seives, meeting ASTM specifications of the following mesh sizes were employed: 12.7, 3.36, 2.00, 0.50, 0.25, 0.125, and 0.045 mm.

All metals, except mercury, were analyzed by the following procedure. Five grams of air-dried, well-mixed sediment were placed in a 250 ml erlenmeyer flask with 50 ml deionized water, 0.5 ml nitric acid (specifid gravity of 1.42), and 5 ml HCL (specific gravity of 1.10). The mixture was heated and maintained at 95° C until the volume was reduced to 15-20 ml. The sample was cooled and cleared by filtering through a glass fiber filter, the volume was adjusted to 100 ml, and analyzed by atomic absorption (Instrumentation Laboratories Model 651).

Mercury concentrations were determined by the following procedure. Sediment (0.2-0.3 g)was weighed and added to a tube with 1.0 ml concentrated nitric acid and 4.0 ml concentrated sulfuric acid. The sample was heated to 58° C for two hours, cooled to 4° C,,then 6 ml of 5% $KMnO_4$ was added, 2 ml at a time. This was repeated until the sample remained purple for at least 5 minutes. Samples were allowed to stand overnight. Hydrogen peroxide (30%) was added dropwise until the precipitate dissolved. Samples were diluted to 100 ml with deionized water and analyzed.

Chlorinated hydrocarbons were determined by mixing damp sediment (50 g) with sodium sulfate until a free-flowing mixture was obtained, and then added to a chromatography column (0.5 cm diameter). The sediment was extracted with 250 ml of acetone-hexane (1:1) at a flow rate of 3-5 ml per minute. The solvent was concentrated to 100 ml and interfering compounds were removed by shaking in a separatory funnel with hexane and distilled

water. The hexane was drawn off and saved, and the hexane-acetone mixture was re-extracted with 15% CH_2Cl_2 in hexane. The two extracts were combined and concentrated under nitrogen to 5 ml. The pesticides are then partitioned on a florisil column and the various pesticide fractions analyzed with a Hewlett-Packard Model 5880 A gas chromatograph equipped with a ^{63}Ni detector.

Tissue Analysis

Tissues of three invertebrate and three vertebrate species were sampled to determine body burdens of both metals and organics. (The majority of the analyses were performed using two species of both vertebrates and invertebrates.) Analysis on one invertebrate and two vertebrates was originally called for, but due to the disparate sample sites (Stations 2, 4, 7, 8, 9, and 12), this proved to be impractical. The specified invertebrate (the mollusk Corbicula manilensis) was plentiful at most lake stations, but poorly represented at others. Fortunately, the mollusk (Anodonta cataracta) was present in sufficient densities to allow an invertebrate sample from all stations and two species from most. The only invertebrate present in analyzable quantities at Station 12 was the crayfish, Cambarus sp.. The designated vertebrates, the largemouth bass (Micropterus salmoides) and the catfish (Ictalurus nebulosus), were available at all sites sampled except for Station 12, where the bluegill (Lepomis macrochirus) was substituted.

Invertebrates were collected by wading or SCUBA diving, while fish were procured by hook and line or purchase. The fish were all caught on station and during the sampling period. All samples were immediately stored and maintained on dry ice until return to the laboratory and long-term freezer storage.

Tissue analysis of invertebrate species was on the whole body (excluding shell), while only the lateral musculature of fish was utilized. All samples represented a composite of at least five individuals.

In order to determine metal concentrations, tissues were homogenized by high speed blending with dry ice until a uniform powder was obtained. Fifty grams of tissue were added to a Pyrex beaker with 25 ml of 20% sulfuric acid and covered with a ribbed watch glass. The sample was heated overnight at 110° C until charred viscous sulfuric acid/sample mixture was obtained. The temperature was then increased to 275° C at a rate of 50° C per hour. Thesample was maintained at 275° C for three hours, then raised to 450° C and held overnight. The samples were allowed to cool, treated with 1.0 ml concentrated nitric acid and 0.5 ml water, and evaporated carefully to dryness. The samples were reheated to 300° C for exactly thirty minutes and cooled. (This was reheated until a carbon-free white ash was obtained.) Ten ml of water and 0.5 ml of nitric acid were added, the sample warmed to 80-90° C for 5-10 minutes, then diluted to 100 ml with deionized water, and analyzed.

Arsenic and selenium samples were digested by the addition of 5 ml of concentrated HNO_3 to a known weight of sample. Six ml of concentrated sulfuric acid were slowly added, then the mixture was covered. The sample was warmed slightly until it turned dark, and an additional 5 ml concentrated nitric acid was added. The mixture was re-warmed until the dark color returned, then cooled. Five ml of 50% hydrogen peroxide were slowly added, the sample was heated until the initial reaction had ceased. After cooling, the procedure was repeated until the dark color disappeared. Forty ml of concentrated HCL were added, the sample was brought to volume with deionized water, and analyzed.

Arsenic and selenium were analyzed by AA using the gaseous hydride technique. Mercury was analyzed by the method outlined in the sediment section.

Tissues were analyzed for organics by extracting 50 gram portions of frozen, ground flesh with 150 ml hexane and 100 g Na_2SO_4 at high speed in a blender. The hexane was decanted and saved, and the residue was re-extracted twice more. The combined hexane extracts were dried with sodium sulfate and concentrated with a Kuderna-Danish apparatus to 10 ml. The sample was partitioned four times with hexane-saturated acetonitrile as a clean-up procedure. The pesticides and PCB were then back extracted into hexane by the addition of 650 ml distilled water to the 120 ml hexane-acetonitrile mixture and then re-extracting twice with 100 ml portions of hexane. The hexane was concentrated and analyzed by electron capture gas chromatography, either directly or after florisil separation.

V RESULTS AND DISCUSSION

A. Meteorology and Hydrology

Air temperatures and the majority of the rainfall information were obtained from National Oceanic and Atmospheric Administration (NOAA) publications supplied by the National Climatic Center in Asheville, North Carolina. The remainder of the rainfall data, as well as all of the hydrological data, was obtained from the United States Corps of Engineer's district office in Savannah, Georgia.

Maximum and minimum daily air temperature values for the 1981 calendar year are given in Appendix A-1. These temperatures were recorded from the Anderson (South Carolina) Airport weather station, located approximately eight kilometers from stations 2, 3, and 8. The highest and lowest temperatures were 101^{0} and 11^{0} farenheit (F) during the hottest and coldest months (June 15, 20, and January 12), respectively.

Average monthly rainfall for Hartwell Lake watersheds in northwest South Carolina, southwestern North Carolina, and northeastern Georgia are presented in Table A-1. Also included are the departures from the normal yearly values. Daily rainfall values recorded at Hartwell Dam are included in Appendix A-2. Overall, the Hartwell watershed received an annual rainfall of more than 12 inches below normal.

Daily releases from Hartwell Dam, daily total inflow to the lake, and daily pool elevations are given in Appendices A-3, A-4, and A-5, respectively. Total average monthly Dam release, and total average input to the lake are presented in Table A-2. Maximum daily inflow to the lake occurred on August 14, with 14,981 day-second-feet (dsf), following a week of rainfall. The minimum amount received was a minus 652 dsf on September 21. This negative value is likely the result of both low runoff and high evaporation. February had the highest monthly inflow (3927 dsf), while October the lowest (1554 dsf).

More water was discharged from Hartwell Dam (for generating purposes) during August (4168 dsf) than any other month while the maximum daily discharge was 10,244 dsf on January 6. The minimum monthly release was in March with 1,854 dsf. No water was discharged during virtually every weekend throughout the year.

With the sub-normal amount of rainfall in 1981 throughout the southeast, the volume of water stored in Hartwell Lake decreased over the year and this decrease is graphically depicted in Figure A-1. Hartwell Lake's pool elevation rose from 653.47 feet above mean sea level (fmsl) on January 1 to a maximum of 655.87 fmsl on June 14. The pool elevation then dropped to a minimum of 642.25 on December 31 for a range during the last six months of over 13.5 feet.

TABLE A-1

Area Rainfall and Departure from Normal

Area	Month J	F	M	A	M	J	J	A	S	O	N	TOTAL
Northwest (S.C.)	0.46	4.66	2.91	1.37	3.58	2.65	3.77	1.90	2.64	3.56	1.43	28.93
	-3.86	0.14	-2.72	-2.91	0.19	-1.55	-1.11	-2.61	-1.18	0.45	-1.93	-17.07
S. Mountains (N.C.)	0.96	5.20	3.64	3.01	5.95	3.53	4.18	1.57	3.42	2.97	1.87	36.30
	-3.42	0.45	-1.98	-1.40	2.02	-1.20	-1.47	-3.51	-0.64	-0.68	-1.76	-13.59
Northeast (Ga.)	0.92	7.02	3.08	2.16	4.09	2.65	4.24	2.68	2.68	3.50	1.64	34.66
	-4.18	1.85	-3.18	-2.65	0.23	-1.91	-1.15	-1.64	-1.28	0.17	-2.17	-15.89

TABLE A-2

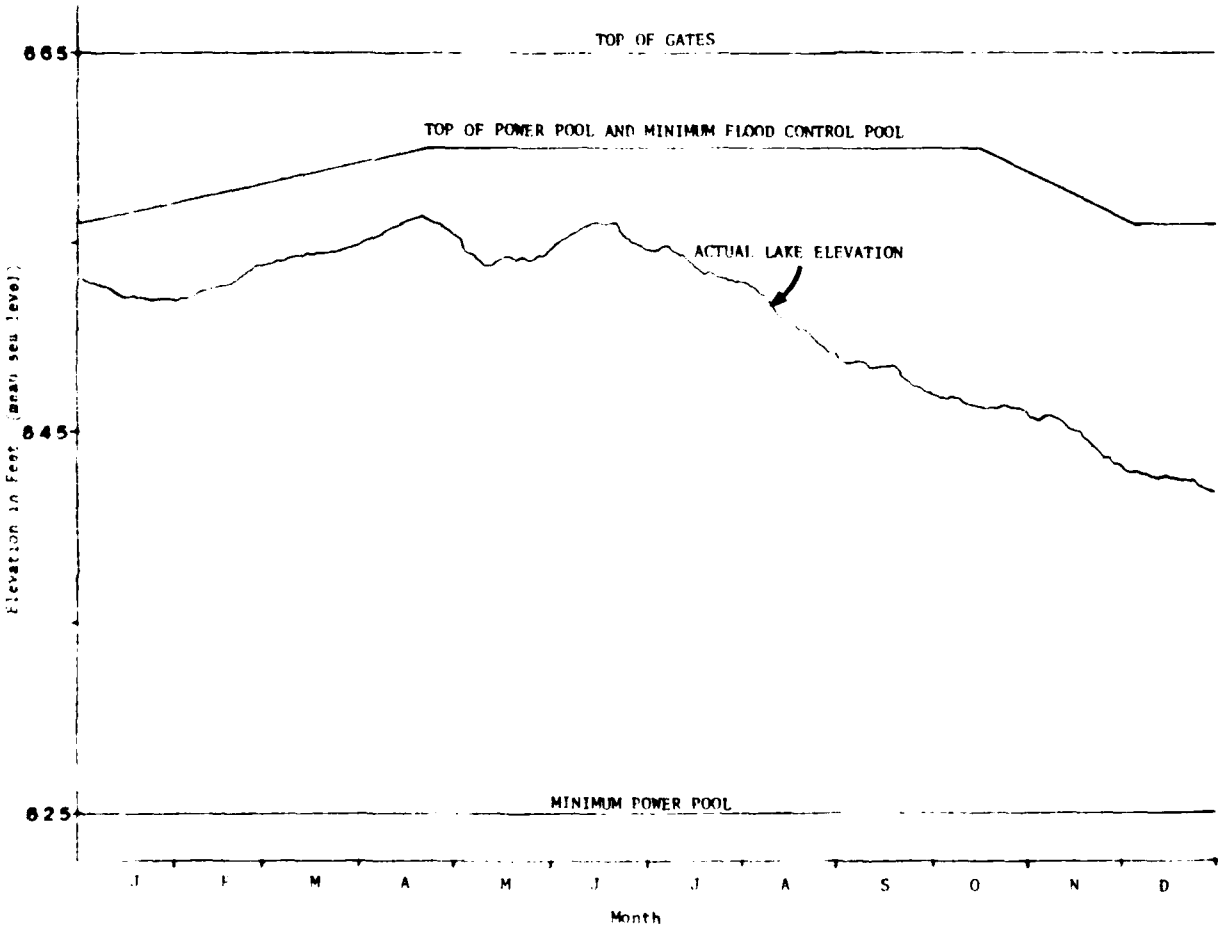
1981 Lake Hartwell Flow Rates

(day-second-feet)

MONTH	DISCHARGE	INFLOW
Jan	2922	2027
Feb	2270	3927
Mar	1854	2294
Apr	1929	2106
May	2394	2257
Jun	2350	2289
Jul	2811	1727
Aug	4168	1660
Sep	2752	1738
Oct	2729	1554
Nov	3098	1610
Dec	2810	2662

Figure A-1

Hartwell Lake Rule Curve



B. Water Quality

Profiled in situ and laboratory water quality results for February, June, and November are presented in Appendices B-1 through B-24. Both profiled and depth-composited water quality data for the August diel study are included in Appendices B-25 through B-33. The remainder of the laboratory results for February, June, November, and for selected August values are in Appendices B-34 through B-59. Keys to all water quality appendices are included and precede the appropriate sections.

Temperature

Seasonal temperature stratification profiles are shown for station 1 (Figure B-1) and are representative of the deeper lake stations (#1, 2, 3, 4, and 6). There was vertical homogeneity at station 1 during February and little variation (5-7^{o}C) among all sampled stations and at all depths. A well developed thermocline was established at 5-6 meters by June and increased insolation had lowered the thermocline to 10-12 meters by August. The mixing of warm surface and cold bottom waters was responsible for the intermediate November values and the further lowering of the thermal discontinuity layer to thirty meters. Hartwell Lake, at station 1, underwent complete thermal destratification (overturn) during December or January.

Temperature isopleths* for the four main lake stations (1, 2, 3, and 4), starting from Hartwell Dam and proceeding up the Seneca arm of the reservoir, are given for the February, June, August, and November sampling periods (Figures B-6 through B-9, respectively). Thermal stratification is again evident during the three warmest months, and is absent during February.

The highest and lowest temperatures recorded during this study both came from inflowing river stations. Station 9, in the Seneca River immediately below Lake Jocassee, was 30.3^{o}C in August while station 10 (Tugaloo River) was 4.0^{o}C in February. Surface temperatures were two degrees Celsius higher in August than in June for Lake stations 1, 2, and 3. Stations 4, 5, and 8, however, were colder in August than in June. This is due to the main body of the lake warming during August to temperatures above those of the inflowing water. The reverse is true in February, where the "uplake" stations are receiving water cold enough to lower their temperature to values 2^{o}C below those of the lower lake stations.

* Caution must be used in the interpretation of all of the isopleth figures. With distances of more than six kilometers separating some sample sites, all isopleth lines are, of necessity, approximations.

FIGURE B-1

STATION 1

STRATIFICATION PROFILES

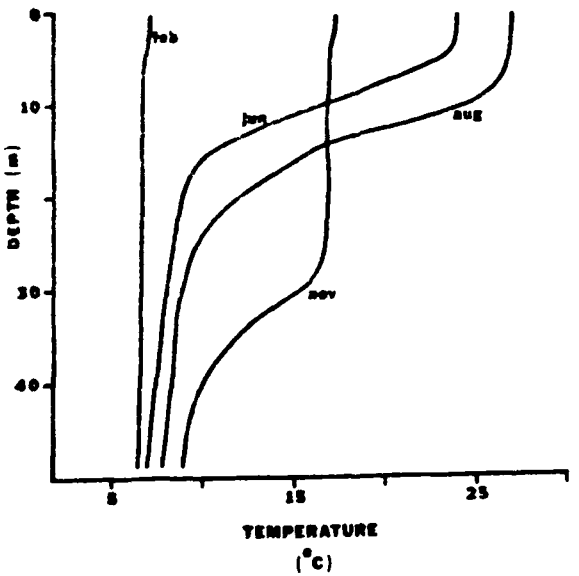


FIGURE B-2

STATION 1

STRATIFICATION PROFILES

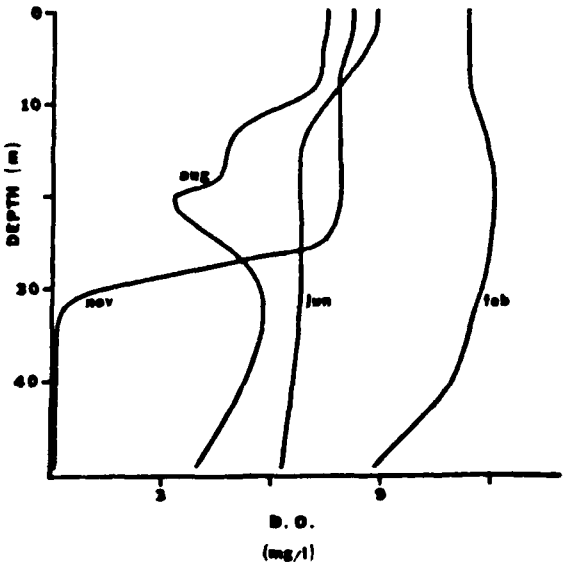


FIGURE B-3

STATION 1

STRATIFICATION PROFILES

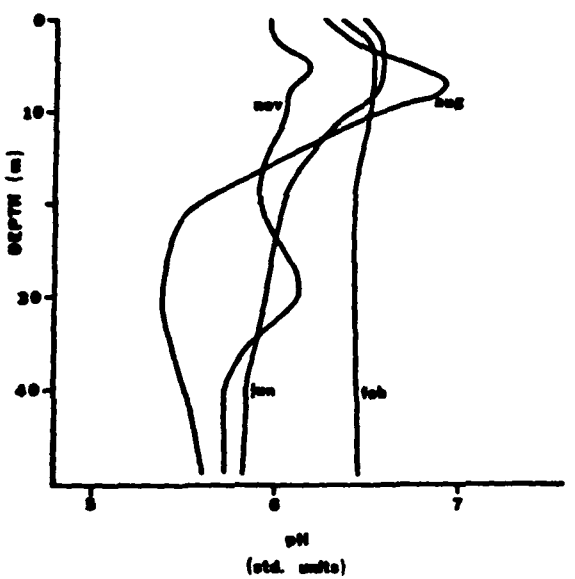


FIGURE B-4

STATION 1

STRATIFICATION PROFILES

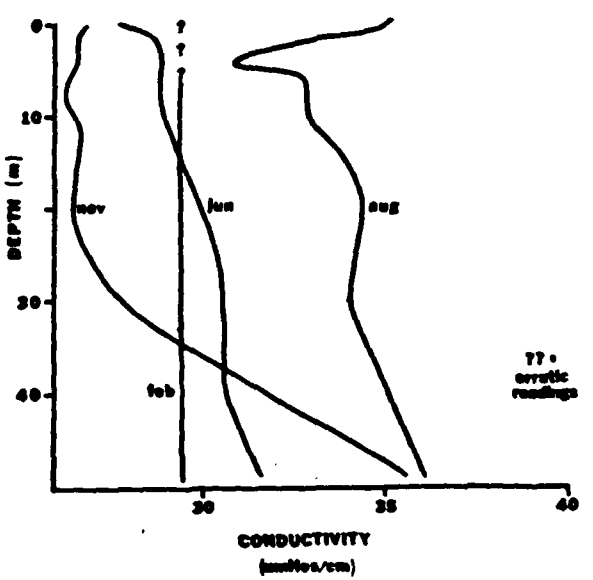


FIGURE B-5

STATION 1

STRATIFICATION
PROFILES

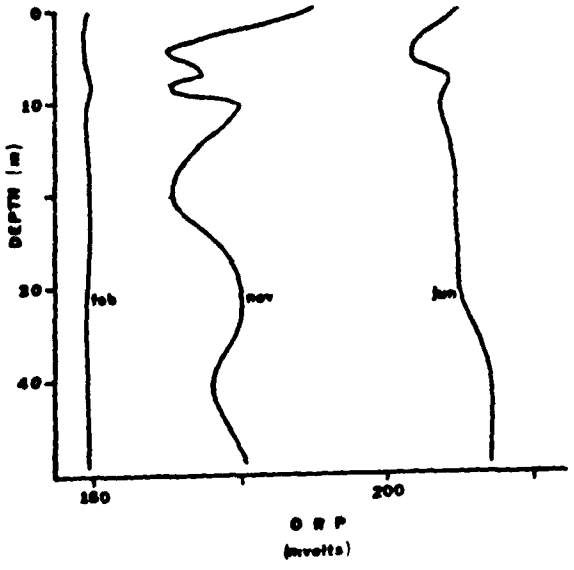


FIGURE B-6

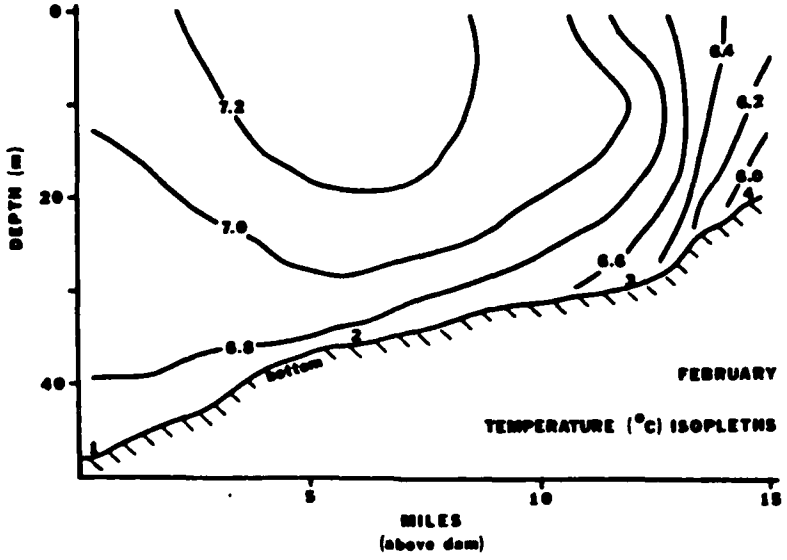


FIGURE B-7

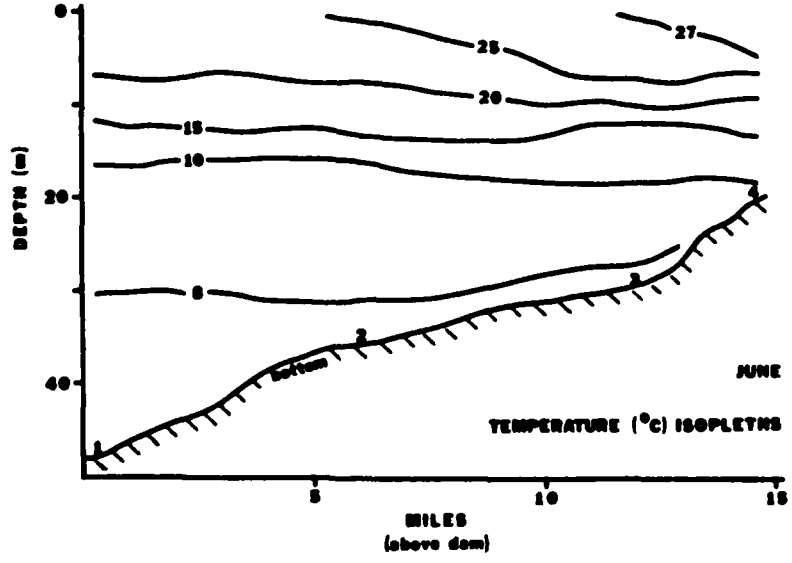


FIGURE B-8

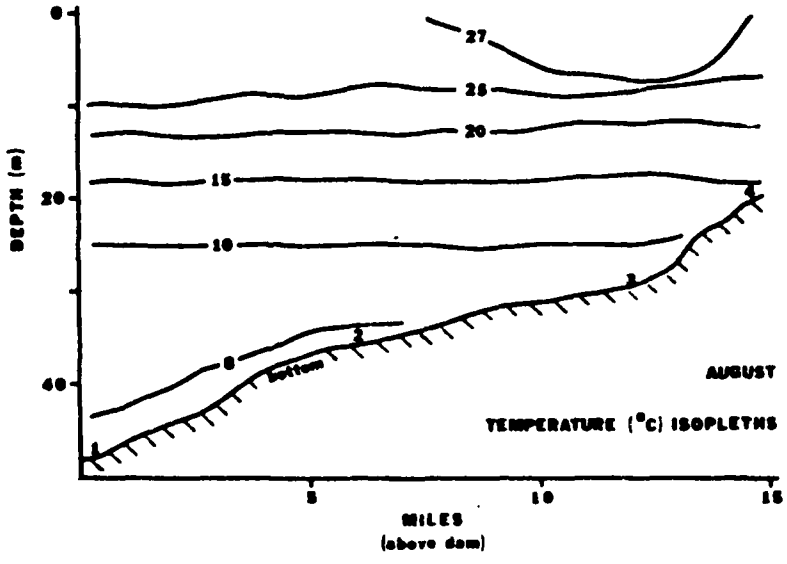
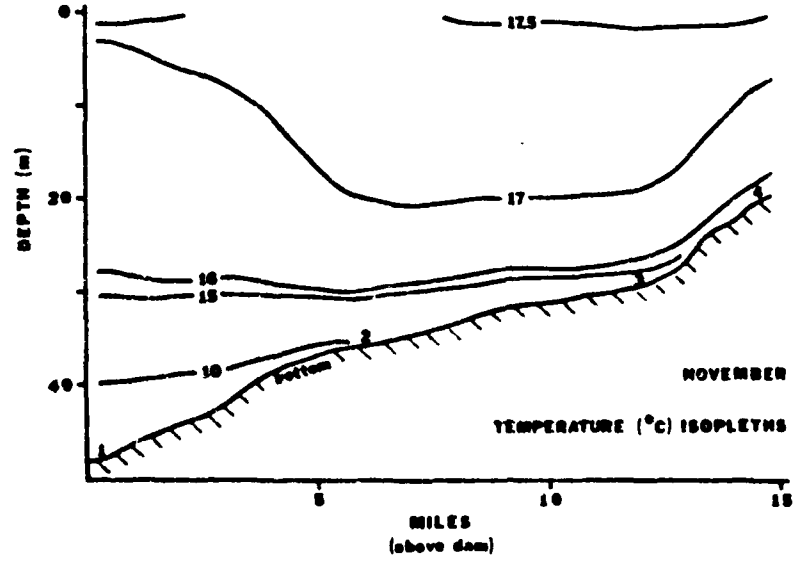


FIGURE B-9



Water is released from station 1 (Hartwell Dam) and then flows by stations 11 and 12 (Savannah River). The temperatures of these river stations during August was 12°C (Appendix B-33) due to cold water being removed from the bottom of the lake. It is unlikely that these river stations ever get appreciably warmer as cold water species (trout,e.g.) thrive year-round. Little warming occurs in the approximately 3 km between stations 11 and 12.

There is a slight diel variation in lake temperatures during August at all stations with the coldest temperatures occurring just after sunrise. The warmest temperatures occur in the late afternoon and all diel variation is above the thermocline and near the surface.

Dissolved Oxygen

Dissolved oxygen (DO) values ranged from undetectable at deep lake stations in November to a maximum of 14.5 mg/l at station 5 in February. Station 5 and several other shallow stations were actually supersaturated with DO during February and this is probably due to wind-induced turbulence. Highest DO values are associated with the lowest water temperatures and there is a trend towards decreasing DO with depth. Seasonal stratification profiles of DO for station 1 are given in Figure B-2. The near-surface waters are well oxygenated throughout the year, but below twenty meters the amount of DO present is highly dependent on the season. During February, when there is no thermocline present and the temperatures are uniformly cold, there is relatively high DO ($\geq$ 9 mg/l) from the surface to the bottom. With the development of the thermocline in June, and then August, there is a decline in DO with depth. By November virtually all of the oxygen has been depleted below thirty meters and these bottom waters will remain anoxic until winter destratification occurs, sometime before February. This anoxia is caused by the continued utilization of oxygen at depth throughout the year, while replenishment from surface production is inhibited by the thermal stratification. The only time that DO levels fell below the South Carolina recommended level for aquatic life of 5 mg/liter was in November and at depth.

Horizontal isopleths for dissolved oxygen also exhibit seasonal stratification as only during February (Figure B-10) do the values show a well-mixed reservoir. The lack of oxygen noted above for station 1 during November (Figure B-2) is not confined to this site but rather the entire bottom appears to be anoxic from Hartwell Dam to station 3, a distance of 12 miles (21 km). Station 3 was the only location low in DO during February, and the levels steadily decreased with depth (Figure B-13). In June and August (Figures B-11 and B-12, respectively) there is a mid-water intrusion of oxygen depleted water at a depth of twenty meters at stations 3 and 4.

FIGURE B-10

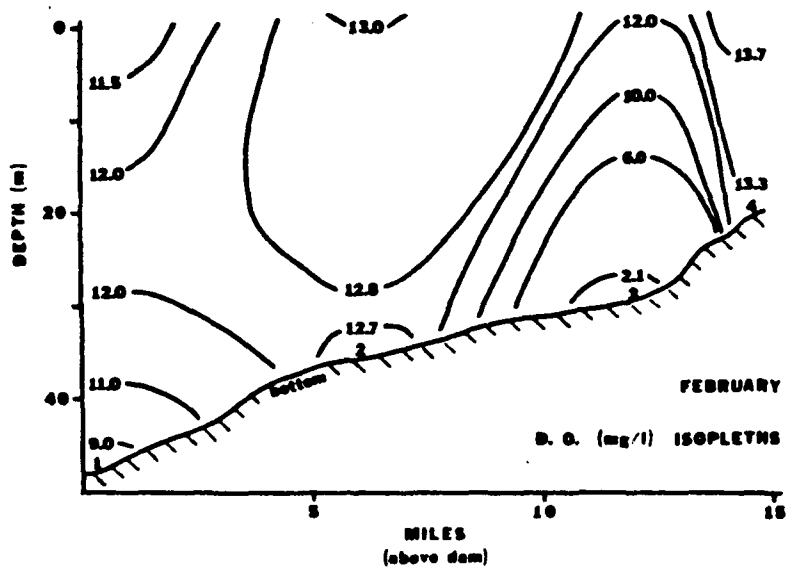


FIGURE B-11

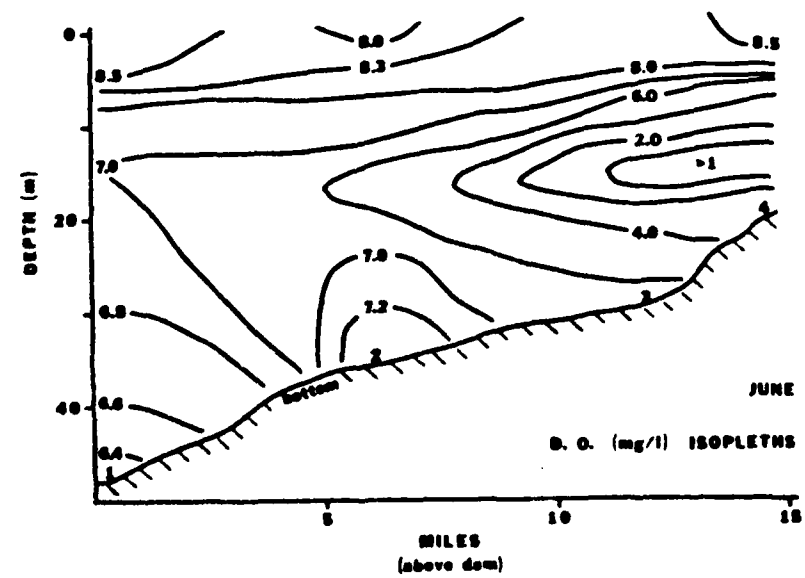


FIGURE B-12

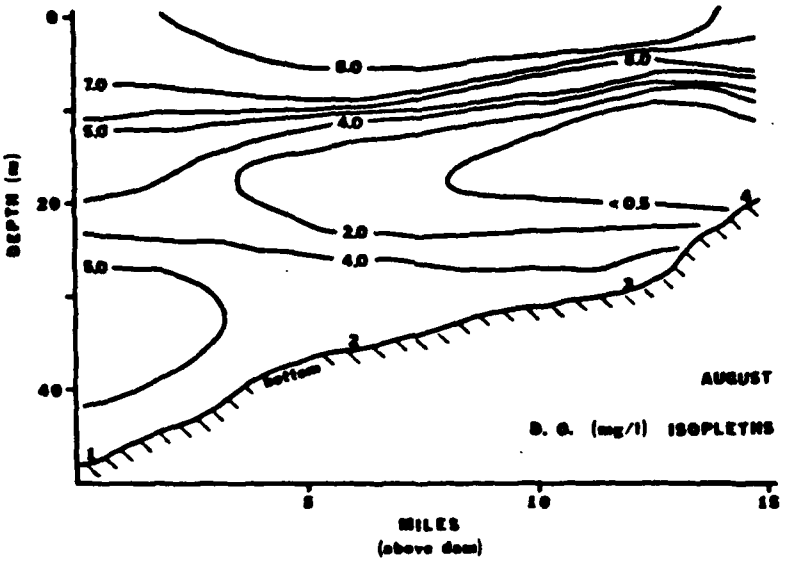
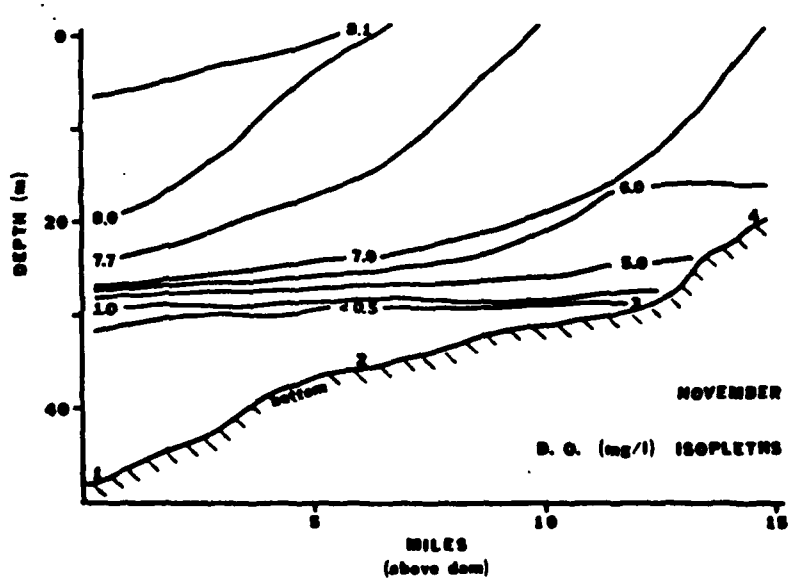


FIGURE B-13



The August study revealed diel fluctuations in DO above the thermocline. Highest values occurred at sunset with minimums being recorded in midmorning and average variations for the eight lake stations were 0.2-0.3 mg/l. This trend is the opposite to the influence that temperature should have on DO concentrations and reflects daytime production and nighttime consumption. The oxygen-depleted water (<5.0 mg/l at depth) at station 1 in August (Appendix B-25) has been reoxygenated (~8.0 mg/l) by the time it reaches station 11 (Appendix B-33), a distance of less than two kilometers.

pH

Stratification profiles for pH at station 1 (Figure B-3) exhibited little vertical variation in February. Values fluctuated widely with depth in August while intermediate values were recorded during June and November. The maximum pH values for all seasons were found at a depth of 5-7 meters, with minimum levels at depths of 30-50 meters. During August, a decrease of 1.5 standard pH units occurred between 10-20 meters, again illustrating the division of the reservoir into two distinct layers during the warmer seasons. pH isopleths for stations 1, 2, 3, and 4 during February, June, August, and November are given in Figures B-14 through B-17, respectively. The maximum and minimum pH values were both recorded from station 8 during August and were 7.2 and 5.05, respectively.

Comparisons between reservoirs located in comparable regions can be of value but, of necessity, must be general due to a variety of factors. This is true of pH measurements and only comparisons with previous Hartwell Lake data will be discussed in this report.

Using the Environmental Protection Agency's STORET file, a total of 172 pH values were located that were recorded earlier from Hartwell Lake sites that were on or near sites corresponding to stations 3, 4, and 5 of the present study. The majority of these (82%) were from 1974-1980, with the rest dating back to 1955. These more recent values appear to reflect a trend for pH to increase away from the dam as the majority of the measurements were less than 6.8 at the location corresponding to station 3 of the present study, while more than 50% of the values were greater than 7.0 at sites near stations 4 and 5 of this study. This trend was apparent in the current study as well as the majority of the values were less than 6.3 and greater than 6.5 at stations 3 and 5, respectively.

As can be seen from the values in the preceding paragraph, there also appears to be a trend towards decreasing pH values with time, suggesting that Hartwell Lake may be becoming more acidic. In addition, a review of all previous pH measurements from Hartwell Lake (using STORET) found the minimum surface value to be 6.00, while the present study resulted in 11% of the total 104 surface values falling below this figure. Although there are a limited number of measurements (11), more than 50% of the values from 1955 were greater than 11.0, while none of the 1,016 total measurements in the current study exceeded 7.2, and 29% (299) were below 6.0

FIGURE B-14

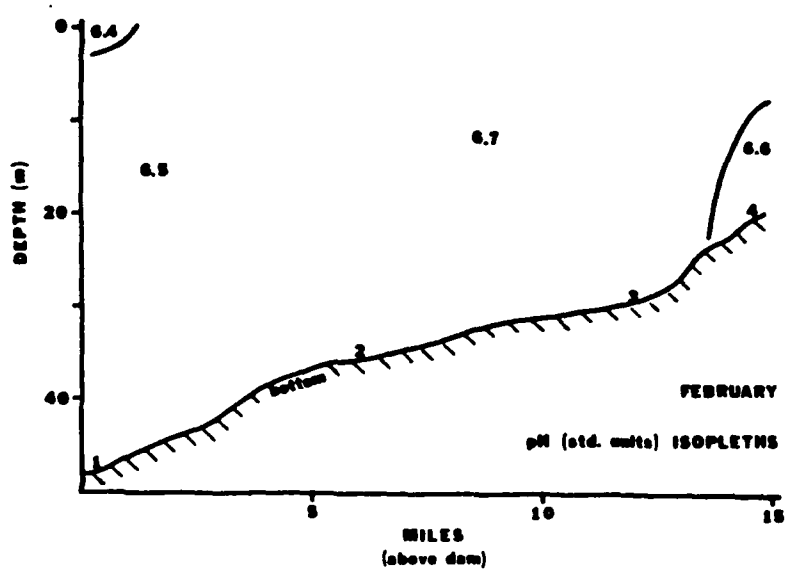


FIGURE B-15

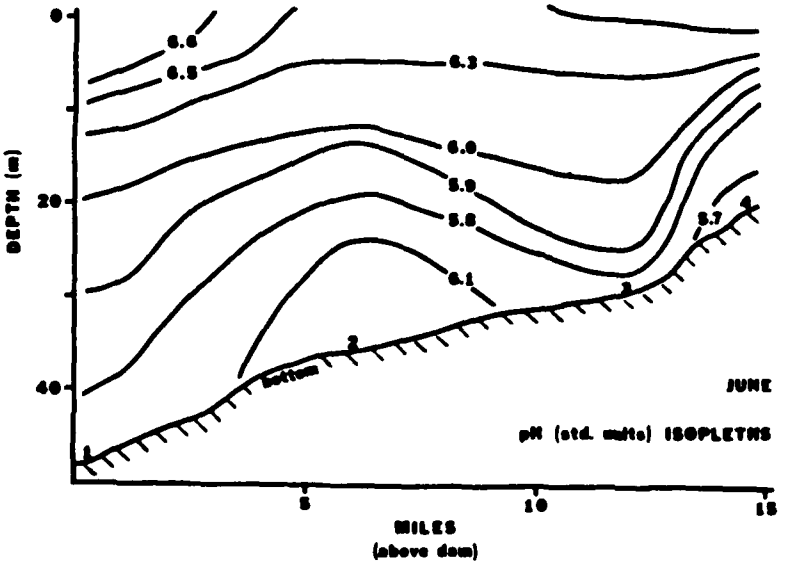


FIGURE B-16

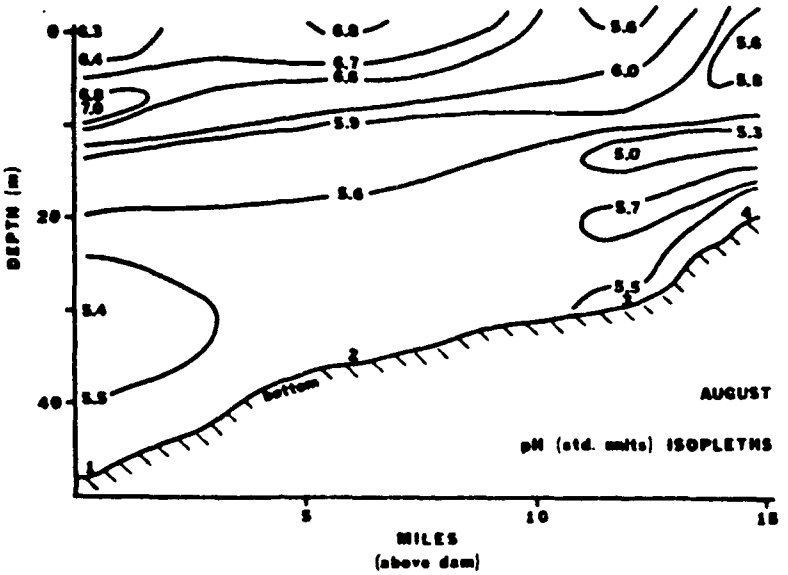
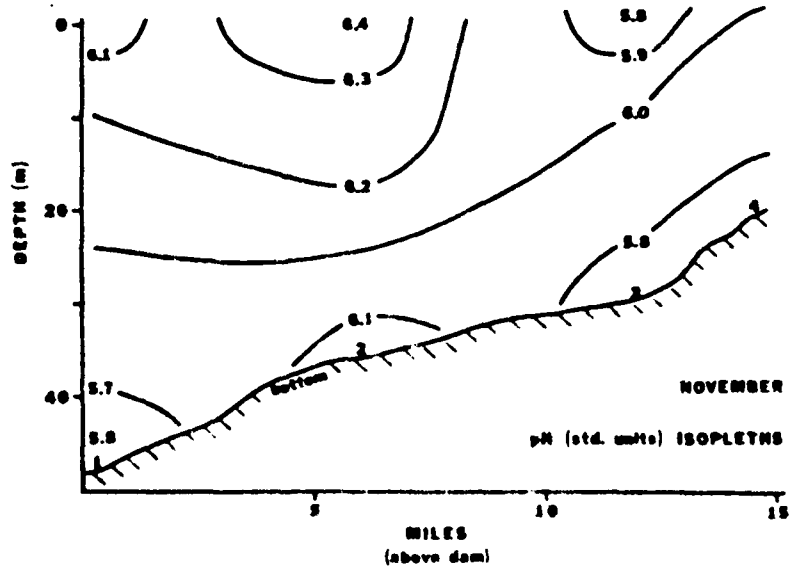


FIGURE B-17



The pH values recorded during the diel study indicated no daily variations for the eight lake stations. There was also no detectable difference in the pH levels of the two branches of the reservoir, the Seneca and the Tugaloo arms. The pH changed little from station 1 (above the dam) to stations 11 and 12 on the Savannah River, although at both station 11 and station 12 the pH values were higher during periods of high flow, i.e. during power generation (Appendix B-33).

The values recorded during the current study indicate that the pH level of Hartwell Lake is similar to that of Lake Keowee, located immediately upstream on the Seneca River arm of the reservoir. Lake Keowee values ranged between 7.0 and 5.5 (Duke Power, 1976).

Conductivity, ORP, and % Light Transmission

Conductivity and ORP seasonal profiles are illustrated in Figures B-4 and B-5, respectively. Higher values for both parameters occur during the warmer months. Conductivity values generally ranged between 25-45 micromhos, although occasionally higher values were recorded from samples taken near the bottom and likely reflect the inclusion of bottom sediment. ORP values averaged 220 millivolts and typically ranged from 170-260 mv. Hartwell Lake has a higher conductivity than Lake Keowee (Duke Power, 1976) with the former averaging 35-40 micromhos and the latter 20 micromhos, although the Lake Keowee values were recorded earlier (1971-1976).

The graphing of isopleths for both conductivity and ORP proved difficult due to the wide scatter in values at the same stations. For this reason, isopleth lines were not added to the diagrams, but rather the individual data points were used to allow comparisons. Conductivity values for stations 1, 2, 3, and 4 for the months of February, June, and November are presented in Figures B-18 through B-20. The same stations and months for ORP measurements are given in Figures B-21 through B-23. There was absolutely no pattern to the August values for both parameters and the inclusion of data points in their respective figures proved confusing; August values for both are listed only in the appropriate appendices. Figure B-24 shows the 1% light penetration isopleths for February and June over stations 1-4.

There were no horizontal trends evident between any of the lake stations for either conductivity or ORP. Conductivity increased with depth at virtually all profiled stations, while there was no evident trend with depth for ORP. Conductivity values were unchanged above (station 1) and below (stations 11 and 12) Hartwell Dam.

Remaining Water Quality Parameters

The remaining water quality data are included in Appendices B-34 through B-59. Seasonal and spatial trends and comparisons with other systems (where possible) will be discussed for individual parameters.

FIGURE B-18

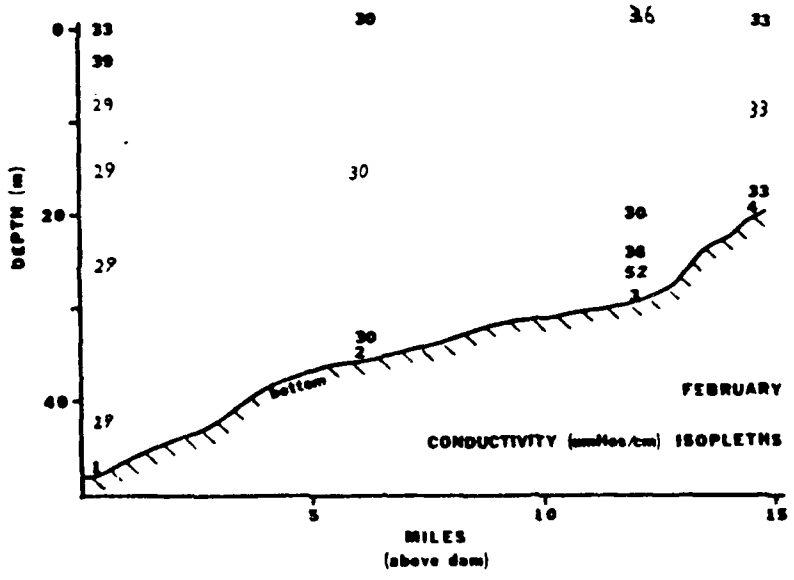


FIGURE B-19

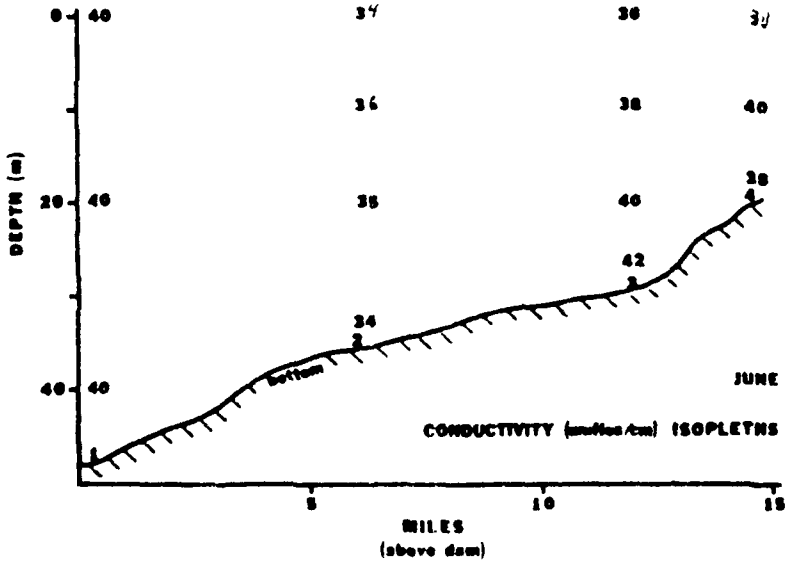


FIGURE B-20

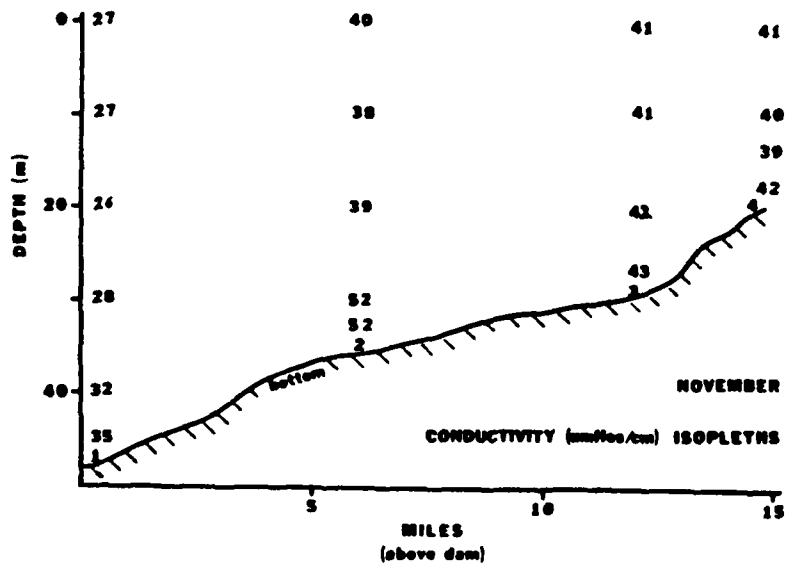

0
20
40
DEPTH (m)
27
27
26
28
32
35
40
38
39
52
52
2
39
41
41
41
40
39
42
43
3
Bottom
NOVEMBER
CONDUCTIVITY (mmhos/cm) ISOPLETHS
5
10
15
MILES
(above dam)

FIGURE B-21

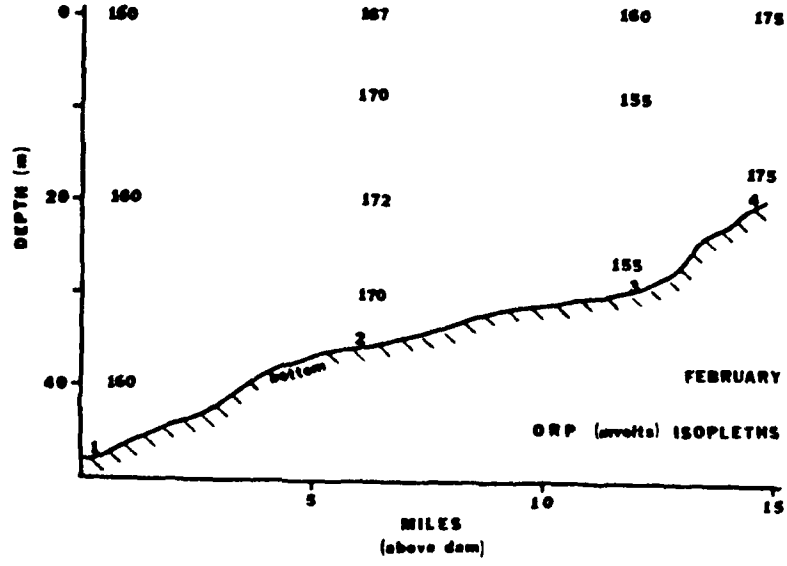


FIGURE B-22

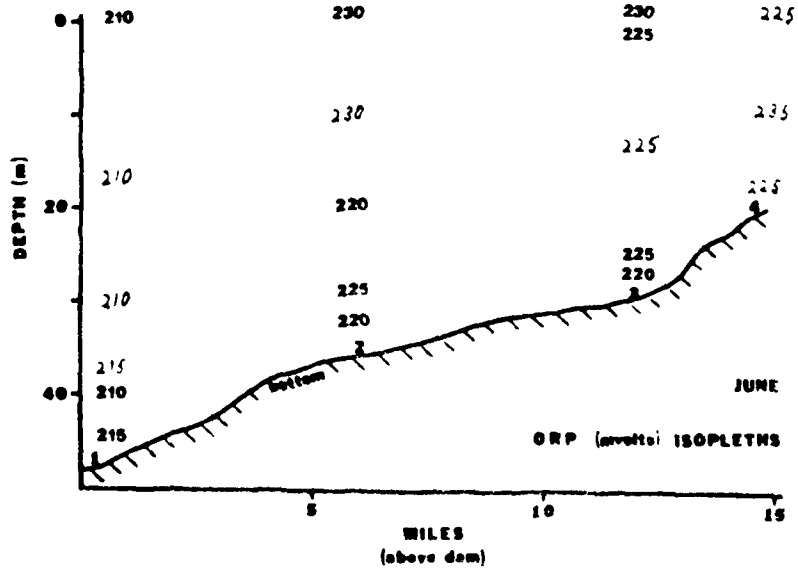


FIGURE B-25

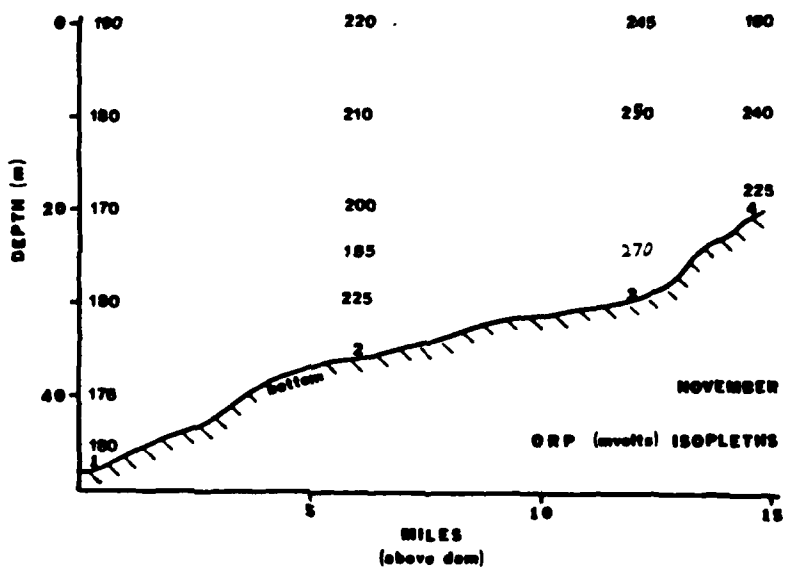
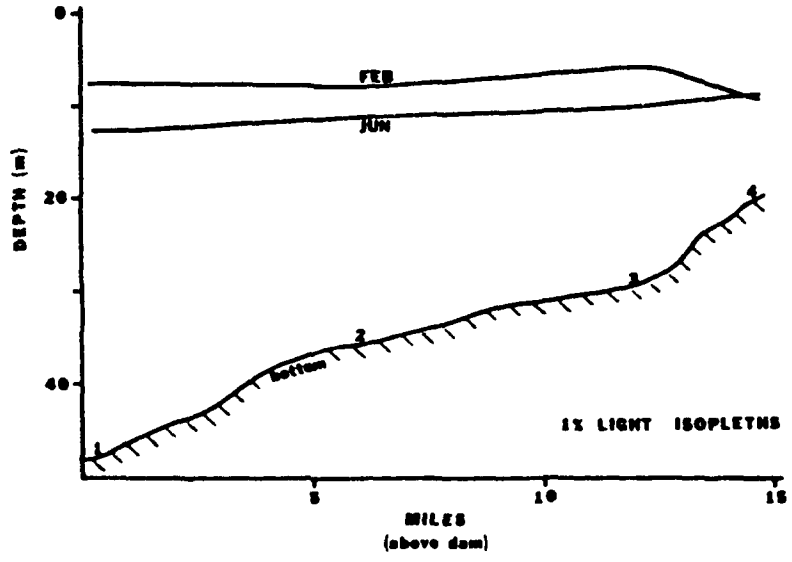

0
20
40
DEPTH (m)
190
180
170
160
176
190
220
210
200
185
225
245
250
270
190
240
225
4
3
2
1
Bottom
NOVEMBER
ORP (mvolts) ISOPLETHS
5
10
15
MILES
(above dam)

FIGURE B-24


0
20
40
DEPTH (m)
FEB
JUN
1
2
3
4
Bottom
1% LIGHT ISOPLETHS
5
10
15
MILES
(above dam)

Total nonfiltrable residue values are given in Appendix B-34. Values averaged less than 10 mg/l for most stations and dates with the exception of the August river stations where values were between 15-30 mg/l. The Tugaloo arm of the reservoir (stations 6 and 7) were appreciably higher than either the main lake stations (1 and 2) or the Seneca arm stations (3 and 4). The reason for the extremely high value (106 mg/l) recorded from station 6 in November is unknown. Calculated mean dissolved solids for Lake Keowee from 1971-1976 was 22 mg/l.

Appendix B-35 lists total filtrable residue measurements and with one exception, there are no seasonal or spatial trends. August river values (stations 9, 10, 11, and 12) averaged 2 mg/l while the same stations averaged over 30 mg/l during the other three sampling periods.

Turbidity values (Appendix B-36) were generally low with November being the only season with significant readings. Only lake stations 2-7 gave values above the minimum and these averaged twice that, or 10 JTU. These values agree with previous levels from Lake Keowee were values were generally below 10 JTU (Duke Power, 1976).

Nitrite and nitrate measurements are presented in Appendix B-37. There is a slight seasonal trend as August and November values are slightly lower than February and June for the lake stations. Values were generally less than 0.25 mg N/l at all stations and all seasons with Station 12 being the exception. Concentrations at station 12 were 2 to 4 times higher than at station 11 suggesting some source exists between the two. Values from the current study are again similar to those reported in the previously cited Lake Keowee study, where maximum concentrations were 0.32 mg N/l.

Ammonia (Appendix B-38) and TKN (Appendix B-39) showed neither spatial nor seasonal trends, and values were usually less than 0.2 and 0. mg/l, respectively.

Phosphate (Appendix B-40) and orthophosphate (Appendix B-41) totaled less than 0.4 mg P/l and increased between Stations 11 and 12. Values were less than 0.4 at Station 11 and approximately 0.7 mg P/l at Station 12. Values agreed well with the range reported from Lake Keowee of 0.1-0.3 mg P/l.

Alkalinity exhibited no trends and values ranged between 2-10 mg $CaCO_3$/l (Appendix B-42).

Appendix B-43 contains free CO_2 data and while there is no spatial trend, a definite seasonal one is indicated. Values averaged 6 mg CO_2/l during February, June, and August and 15 mg CO_2/l in November.

Color gave both a seasonal and a limited spatial trend (Appendix B-44). Values were less than detectable in June (<2 Pt-Co units), 4-5 units in February, and generally 5-10 units in November. The horizontal trend occurred only during November, where lake stations 2-8 were appreciably higher than station 1 or the four river stations.

Total organic carbon was fairly uniformly distributed over space and time although there was a slight tendency towards lower concentrations in February versus the other three months. Values were typically less than 3 mg C/l (Appendix B-45).

Appendices B-46 through B-49 give the results for total iron, Fe II, total manganese, and dissolved manganese, respectively. All four species have the same patterns; no spatial trends but higher values in November than throughout the rest of the year. Total iron ranged from approximately 50-to 1,000 ug Fe/1, with concentrations in February and June from 50-600 and in November from 100-1,000. Iron II values were not detectable at any time except November where they ranged from 10-700 ug Fe/1. Total manganese ranged from 10-70 ug Mn/1 during February and June, except for relatively high values at Stations 7 and 8 in June. The range for total Mn in November was 20-350 ug Mn/1. Dissolved Mn was detected only in November, with concentrations between 10-380 ug Mn/1.

The following five parameters exhibit no discernible trends and only the ranges of the values will be given here. All data can be found, in the following order, in Appendices B-50 through B-54. Dissolved sulfide ($<$ .02-.14 mg S/1), total sulfate (0.1-3.0 mg SO_4/1), total calcium (0.81-4.68 mg Ca/1), total magnesium (0.46-1.55 mg Mg/1). and hardness (3.8-15.3 mg $CaCO_3$/1) are presented.

Appendices B-55 through B-57 give total sodium, total potassium, and chloride data. The only trend present, and common to all three, is for an increase in values between station 11 and station 12. Sodium values ranged from 1.32-11.18 mg Na/1, potassium from 0.6-2.6 mg K/1, and chloride from 0.1-8 mg Cl/1.

Biological oxygen demand showed no trend and values were often below the detection limit. Ranges were $<$ 1-4 mg/1 (Appendix B-58). Chemical oxygen demand also resulted in no discernible trends and values ranged from 0-13.6 mg/1 (Appendix B-59).

South Carolina has adopted maximum contaminant levels for Class B, or recreational, waters from EPA-established drinking water standards. These levels (for various parameters) are presented in Table B-1. Levels recorded from this study all meet these recommended standards, with the following exceptions. Maximum total iron values were approximately three times the recommended level of 300 ug/1, while maximum total manganese values were seven times the recommended concentration of 50 ug Mn/1. Numerous pH readings observed during the present study fell below the lowest recommended level of 6.5 standard units and pH seems to be the one water quality parameter that may be cause for concern.

Bacteriology

Bacteriology results for the twelve sampled stations are given in Table B-2. South Carolina and Georgia have established a limit of 200 fecal coliform organisms per 100 mls water for recreational waters. This limit was not exceeded in any lake stations. Station 11, located immediately below Hartwell Dam, was the only station to surpass this level, averaging 445 MPN/100 ml for two same-day samples collected during August. A slight seasonal trend was evident, with the number of positive samples for all stations being 21, 17, and 12 for August, November, and February, respectively. In general, stations on the Seneca arm of the reservoir were higher than those on the Tugaloo arm.

TABLE B-1

Recommended Maximum Contaminant Levels[a]

Parameter	Levels
**Total Solids	500 mg/l
Turbidity	5 t.u.
**Color	15 c.u.
Alkalinity	No. est. limits
Calcium	No. est. limits
Magnesium	No. est. limits
Hardness	No. est. limits
Sodium	No. est. limits
**Iron	0.3 mg/l
**Chlorides	250 mg/l
**pH	6.5-8.5 pH units acceptable
**Manganese	0.05 mg/l
**Copper	1.0 mg/l
**Zinc	5.0 mg/l
Potassium	No.est. limits
*Mercury	0.002 mg/l
*Chromium	0.05 mg/l
*Cadmium	0.01 mg/l
*Lead	0.05 mg/l
*Arsenic	0.05 mg/l
*Barium	1.0 mg/l
Cyanide	0.2 mg/l
*Selenium	0.01 mg/l
*Silver	0.05 mg/l
**MBAS	0.5
CCE	0.2 mg/l
*Nitrate	10 mg/l
Nitrite	1 mg/l
Phosphate	No est. limits
**Sulfate	250 mg/l

[a] These are limits established according to EPA's primary and secondary drinking water standards. In addition, these are South Carolina's maximum allowable levels for Class B (recreational) waters.

*Indicates maximum contaminant levels of primary standards.
**Indicates maximum contaminant levels of secondary standards.

TABLE B-2

Fecal Coliform (MPN/100 ml)

Site	Station #	2/8/81	8/8/81	11/4/81
Saddler's Creek State Park	13	< 2	< 2	5
		< 2	< 2	2
Anderson City Park	14	23	< 2	< 2
		49	2	2
Oconee Point	15	< 2	6	< 2
		2	5	< 2
Twelve Mile Park	16	170	9	2
		220*	13	11
Holder's Access	17	< 2	130	13
		< 2	49	13
Station 9		< 2	9	13
		< 2	22	13
Hart Park	18	< 2	5	< 2
		< 2	2	< 2
Tugaloo Park	19	2	2	< 2
		< 2	7	< 2
Stevens County Access	20	2	8	2
		< 2	22	5
Station 10		5	2	8
		2	5	5
Station 11		< 2	350*	5
		2	540*	8
Station 12		5	23	2
		2	23	8
Total Positive Samples		12	21	17

*Exceeds S.C. level established for recreational water.

PHYTOPLANKTON AND PERIPHYTON

Phytoplankton Biomass

Chlorophyll *a* and phaeophytin *a* concentrations from each sampling trip are given in Tables C-1 and C-2, respectively. Stations 1, 2 and 6 consistently had the lowest chlorophyll, while Stations 5, 7 and 8 had the highest. Chlorophyll concentrations varied during the study from 1.85 $\mu g \cdot l^{-1}$ at Station 2 to 24.9 $\mu g \cdot l^{-1}$ at Station 8. Interestingly, both measurements were made in February when phytoplankton populations and thus chlorophyll *a* were expected to be low throughout the lake. Generally, highest chlorophyll biomass was found in the spring, followed by fall, winter and summer in that order. Lowest biomass was seen in August, following stratification (Table C-3).

Lake Hartwell can be divided into three major divisions: 1. Seneca River (Stations 3, 4, 5 and 8); 2. Tugaloo River (Stations 6 and 7); 3. Savannah River (Stations 1 and 2 --- below the confluence of the Seneca and Tugaloo Rivers). By ranking these three divisions according to their mean chlorophyll concentration, it is seen that the Seneca River division consistently had the highest chlorophyll *a*, with the Tugaloo next, followed by the Savannah River (Table C-3). Generally, chlorophyll *a* increased as samples were taken progressively upriver, away from the dam, regardless of which lake division was sampled (Table C-1).

Phaeopigments essentially followed trends as reported above for chlorophyll *a* and were usually less than 25% of the chlorophyll concentration, except in August following stratification of the lake, when they exceeded that and were as much as 65% of chlorophyll *a* at station 6 (Tables C-1 and C-2).

Phytoplankton, as measured by cell enumeration and chlorophyll *a* concentrations were within normal limits for large mixotrophic to eutrophic lakes (eg. Wetzel, 1975). It is likely that the gradients of phytoplankton biomass noted in each division of the lake were due to inputs of inorganic nutrients from watersheds upstream being taken up, processed and incorporated into the phytoplankton and transferred in an organic form through the trophic web as the water masses in the lake move slowly toward the dam. However, we found no consistent, statistically significant correlations between the phytoplankton biomass and any constituent measured in the water chemistry at any station. Algae are rapid and efficient processors of nutrients, particularly phosphorus and nitrogen (eg. Wetzel, 1975), thus our measurements of phytoplankton biomass probably reflected metabolic, physiological and reproductive events that occurred in response to inputs of nutrients previous to the times of our collections.

TABLE C-1

Mean Chlorophyll a

(ug/l)

Station	Feb. 5-12	Apr. 4-5	Jun. 5-7	Aug. 1-7	Nov. 1
1	2.48	2.37	2.75	2.40	3.23
1A*	2.35	2.37	2.75	2.45	3.32
1A**					3.26
2	1.85	4.67	3.54	2.61	2.76
2A	1.85	4.60	3.57	2.77	2.75
2A**			3.63	2.86	
3	10.20	10.40	4.84	4.70	3.34
3A	8.06	11.80	4.89	4.70	3.48
3A**		10.05			
4	8,87	10.70	5.12	5.56	8.64
4A	8.06	10.70	5.87	5.55	8.69
4A**	9.14				8.55
5	8.40	19.80	7.75	5.54	22.60
5A	9.94	20.30	8.22	5.78	23.10
5A**		19.50			
6	1.73	5.59	2.85	2.56	2.61
6A	1.68	6.06	3.43	2.49	2.54
6A**				2.63	
7	9.00	9.29	5.49	6.58	11.50
7A	10.30	9.28	5.59	6.41	11.80
8	24.90	24.30	9.75	8.47	22.70
8A	24.70	23.90	9.24	7.95	22.00
8A**	23.90		9.24		

A* indicates a field duplicate

A** indicates a laboratory duplicate

TABLE C-2

Mean Phaeophytin a

(ug/l)

Station	Feb. 5-12	Apr. 4-5	Jun. 5-7	Aug. 1-7	Nov. 1
1	0.944	0.413	0.630	0.817	0.380
1A*	0.796	0.412	0.650	0.824	0.536
1A**					0.527
2	0.768	0.628	0.780	1.270	0.387
2A	0.861	0.537	0.790	1.150	0.539
2A**			0.790	1.150	
3	2.550	2.63	1.16	1.67	1.22
3A	2.17	2.64	1.17	1.59	0.861
3A**		2.24			
4	4.50	3.25	1.47	2.24	3.14
4A	4.15	2.95	1.68	2.17	2.56
4A**	4.77				3.12
5	3.34	1.50	2.16	1.79	4.48
5A	4.17	1.56	2.45	1.51	4.99
6	0.777	1.80	0.64	1.67	0.771
6A	0.801	1.60	0.64	1.37	0.858
6A**				1.22	
7	3.13	2.59	1.54	2.87	2.55
7A	3.12	2.17	0.89	2.56	2.00
7A**		2.60			
8	5.41	3.86	2.68	2.06	3.04
8A	7.62	4.51	2.46	1.99	3.08
8A**	8.11		2.46		

A* indicates a field duplicate

A** indicates a laboratory duplicate

TABLE C-3

Ranges of chlorophyll *a* by season and a comparison of mean values of chlorophyll calculated for the three major divisions of Lake Hartwell (see text). Chlorophyll units are ug chlorophyll *a* · l^{-1}. Numbers in parentheses are station numbers.

SEASON	OVERALL RANGES	SAVANNAH R.	SENECA R.	TUGALOO R.	ALL STATIONS
Winter (February)	1.85(2)-24.9(8)	2.13	12.9	5.68	8.38
Spring (April)	2.37(1)-24.4(8)	3.50	16.5	7.56	11.0
early Summer (June)	2.75(1)-9.75(8)	3.16	6.96	4.34	5.35
late Summer (August)	2.40(1)-8.47(8)	2.57	6.04	4.53	4.80
Autumn (November)	2.54(6)-23.1(5)	3.01	14.3	7.11	9.69

Biomass in the Seneca River was consistently higher than in the Tugaloo or Savannah Rivers (Tables C-1, C-3, C-5 and C-6). This is likely due to greater nutrient inputs by the more populated portions of the lake. It is reasonable to assume that the towns of Clemson and Anderson and the relatively high populations in their vicinities add significantly to the fertility of the lake, though this assumption was not borne out by our measurements of inorganic nutrients -- probably for the reasons given above.

Highest phytoplankton biomasses were consistently measured at station 5 and 8. Station 5 was a blind, unpopulated cove with little probability of significantly mixing with the main body of the lake. Station 8 was on Twenty-six-mile Creek well into the town of Anderson, SC and was bordered with homes, farms and industries. Both stations were the shallowest stations monitored during the study (less than 10 M). Although no significant correlations were found between phytoplankton biomass and the concentrations of nutrients in this study, the high biomass could reflect rapid and efficient turnover of nutrients by the trophic components of the euphotic zone, or possibly to low grazing pressure. In support of the latter possibility, zooplankton concentrations at stations 5 and 8 were generally in the middle of the range for a given sample period, except at station 8 in June, when zooplankton and phytoplankton concentrations were both the highest. Shallow bays, coves and feeder creeks are well known for supporting spawning and for the growth and development of larval fish populations and are thus potential "hot spots" of phytoplankton productivity as well. These shallow areas should be a focus of future studies.

In 1981, Hartwell Lake dropped 18 feet below normal due to lower than normal precipitation. However, the biomass and community composition of the phytoplankton were within normal limits. There were no indications that the phytoplankton were affected by the low water conditions.

Phytoplankton Populations

One Hundred ninety four taxa were identified in the lake samples over the study (Table C-4). They are listed by season and station with their concentrations in Appendices C-1 through C-5. In general the concentration of phytoplankton cells and units followed the same trends as seen above in those of chlorophyll, with lowest concentrations consistently measured at Stations 1, 2 and 6 and highest concentrations at Stations 5, 7 and 8. Cell counts varied from 8.13×10^5 cells $\cdot$ 1^{-1} at Station 1 in February to 3.5×10^7 cells $\cdot$ 1^{-1} at Station 7 in April. Generally, the highest cell counts were measured in the spring and the lowest in the winter, with the summer and fall concentrations falling in between (Table C-5). Like chlorophyll, cell concentrations were highest in the Seneca River division of the lake, followed by the Tugaloo and the Savannah River divisions (Table C-5). There was a distinct trend of increasing cell concentrations in samples taken progressively away from the dam, regardless of which lake division was sampled (Table C-6).

TABLE C-4

Taxa Of Phytoplankton Enumerated in Hartwell Lake in 1981

Division Cyanophyta

Agmenellum quadraduplicatum
Anabaena circinalis
Anabaena confervoides
Anabaena sp. 1
Anabaena sp. 2
Anabaena sp. 3
Anacystis incerta
Anacystis montana
Aphanocapsa sp. 1
Aphanotheca sp. 2
Coelosphaerium sp. 1
Dactylococcopsis musicola
Gloeocapsa sp. 1
Lyngbya geminata
Oscillatoria sp. 1

Division Chlorophyta

Actinastrum hantzschii v. fluviatile
Ankistrodesmus convolutus
Ankistrodesmus falcatus
Ankistrodesmus falcatus v. acicularis
Ankistrodesmus falcatus v. miniatilis
Ankistrodesmus falcatus v. tumidus
Ankistrodesmus nonconselene
Arthrodesmus convergens
Arthrodesmus incus
Arthrodesmus incus v. extensus
Asterococcus spinosus
Botryococcus sudeticus
Carteria sp. 1
Characium limneticum
Chlorella sp. 1
Chodatella longiseta
Chodatella quadriseta
Closteriopsis longissima
Coelastrum sphaericum
Cosmarium isthmium
Cosmarium sp. 1
Cosmarium sp. 2
Cosmarium sp. 3
Crucigenia crucifera
Crucigenia quadriseta
Crucigenia tetrapedia
Dictyosphaerium ehrenbergianum
Dictyosphaerium planktonicum
Dictyosphaerium pulchellum
Dysmorphococcus variabilis
Elakatothrix gelatinosa
Eudorina elegans
Eudorina sp. 1
Francea ovalis
Gloeocystis botryoides
Gloeocystis planktonicum
Golenkinia radiata
Golenkinia radiata v. brevispina
Goniom sociale
Kirchneriella elongata
Kirchneriella lunaris
Kirchneriella obesa
Kirchneriella subcolitaria
Lauterbornielia elegantissima
Micractinium pusillum
Mougeotia sp. 1
Oocystis elliptica
Oocystis sp. 1
Oocystis sp. 2
Pandorina morum
Pediastrum biradiatum
Pediastrum duplex v. gracillimum
Pediastrum tetras
Pediastrum tetras f. evoluta
Pediastrum tetras v. tetradon
Planktonema lauterbornii
Quadrigula chodati
Quadrigula closteriodes
Scenedesmus acuminatus
Scenedesmus armatus
Scenedesmus armatus v. bicaudatus
Scenedesmus bijuga
Scenedesmus denticulatus
Scenedesmus hystrix
Scenedesmus intermedius
Scenedesmus longus
Scenedesmus quadricauda
Scenedesmus serratus
Scenedesmus sp. 1
Scenedesmus sp. 2
Scenedesmus sp. 3
Schroederia setigera
Selenastrum minutum
Selenastrum westii
Selenastrum sp. 1
Sphaerocystis schroeteri
Staurastrum aspinosum v. annulatum
Staurastrum chaetoceras
Staurastrum clevei
Staurastrum dejectum
Staurastrum furcigerum
Staurastrum hirsutum
Staurastrum manfeldtii
Staurastrum manfeldtii v. fluminense
Staurastrum paradicum
Staurastrum protectum v. planktonicum
Staurastrum sp. 1

TABLE C-4

Taxa Of Phytoplankton Enumerated in Hartwell Lake in 1981

Staurastrum sp.1
Tetraedron arthrodesmiforme
Tetraedron caudatum
Tetraedron minimum
Tetraedron tetragonium
Tetraedron trigonum
Tetraedron trigonum v. setigerum
Tetraedron sp. 1
Tetraedron sp. 2
Treubaria setigerum

Division Cryptophyta

Cryptomonas marsonii
Cryptomonas ovata
Cryptomonas sp. 1
Cryptomonas sp. 2

Division Chrysophyta

Chrysochromulina sp. 1
Dinobryon acuminatum
Dinobryon bavaricum
Dinobryon cyclindricum
Dinobryon pediforme
Dinobryon sertularia
Dinobryon sociale
Mallomonas caudata
Mallomonas elliptica
Mallomonas majorensis
Mallomonas producta
Mallomonas tonsurata
Mallomonas sp. 1
Ochromonas sp. 1
Ophiocytium parvulum
Pseudotetradon neglectum
Rhizochrysis limnetica

Division Bacillariophyta

Achnanthes microcephala
Asterionella formosa
Asterionella formosa v. gracillima
Asterionella gracillima
Attheya zachariasi
Cyclotella meneghiniana
Cyclotella stelligera
Fragilaria capucina
Fragilaria construens
Fragilaria construens v. pumila
Fragilaria crotonensis
Fragilaria sp. 1
Frustrulia viridula
Gomphonema parvulum
Gomphonema sp. 1
Melosira ambigua
Melosira granulata
Melosira granulata v. angustissima
Melosira italica v. alpigena
Navicula cryptocephala
Navicula exigua
Navicula sp. 1
Navicula sp. 2
Nitzschia acicularis
Nitzschia palea
Nitzschia sp. 1
Nitzschia sp. 2
Nitzschia sp. 3
Pinnularia biceps
Pinnularia sp. 1
Pinnularia sp. 2
Rhizosolenia eriensis
Rhizosolenia longiseta
Synedra delicatissima
Synedra filiformis
Synedra rumpens v. scotia
Synedra sp. 1
Synedra sp. 2
Tabellaria fenestrata

Division Pyrrhophyta

Ceratium hirundinella
Gymnodinium spp.
Peridinium aciculiferum
Peridinium wisconsinense
Peridinium sp. 1
Peridinium sp. 2
Peridinium sp. 3
Peridinium sp. 4

Division Euglenophyta

Euglena acus
Euglena ehrengerbii
Euglena elastica
Euglena intermedia
Euglena polymorpha
Euglena sp. 1
Phacus brevicauda
Phacus sp. 1
Phacus sp. 2
Trachelomonas horrida
Trachelomonas superba
Trachelomonas volvicina
Trachelomonas sp. 1
Trachelomonas sp. 2

TABLE C-5

Ranges of cell enu[illegible]tions by season and a comparison of mean values of cell counts calculated for the three major divisions of Lake Hartwell (see text). Cell concentrations are in units of cells x $10^6 \cdot l^{-1}$. Numbers in parentheses are station numbers.

SEASON	OVERALL RANGES	SAVANNAH R.	SENECA R.	TUGALOO R.	ALL STATIONS
Winter (February)	0.813(1)-30.2(8)	1.02	10.8	2.99	5.90
Spring (April)	1.85(1)-35.1(5)	2.50	18.4	7.68	11.7
early Summer (June)	2.04(1)-22.2(8)	2.63	12.3	3.87	7.75
late Summer (August)	3.62(1)-13.3(7)	3.83	10.8	7.59	8.23
Autumn (November)	1.66(1)-24.9(5)	2.00	11.7	7.95	8.34

TABLE C-6

Mean Concentration of Phytoplankton Cells Arranged Geographically By Lake Division Showing Progressively Increasing Concentration Away From The Dam

Lake Division	Station	Season Feb	Apr	Jun	Aug	Nov
Savannah River	1 (dam)	83.1*	205	216	385	219
	2	99.2	296	314	389	175
Tugaloo River	6	147	727	247	277	270
	7	534	809	526	1220	1320
Seneca River	3	257	917	700	862	273
	4	420	1180	818	1180	592
	5	720	2915	1305	1245	2220
Twenty-Six Mile Creek	8	2910	2365	2010	1009	1605

* All concentrations $x10^4$ cells per liter

It was apparent that the seasonal and geographic trends in the cell enumerations followed closely those seen in chlorophyll a. Linear regression analysis confirmed this observation (Table C-7).

February samples were largely dominated by diatoms, except at Station 8 where flagellates dominated (Appendix C-6). Flagellates and monads dominated in April, June, August and November at most stations, though in August the Cyanophyta were also important contributors to the phytoplankton biomass (Appendix C-7 to C-10). Flagellates and monads frequently comprised in excess of 50% of the total cells counted. These cells (mostly less than 5 micrometers in diameter) were largely unidentifiable because of their small size and/or because of inadequate preservation. An undetermined number of taxa, probably comprising several algal divisions, were lumped into this category.

Although never dominant, the green algae (Chlorophyta) were the most diverse, contributing 97 or 50.0% of the taxa of phytoplankton identified in this study. The Chlorococcales were the most ubiquitous order of green algae observed throughout the year. Diatoms (Bacillariophyta) contributed 39 taxa (20.1%), followed by the Chrysophyta with 17 taxa (8.8%), the Cyanophyta with 15 taxa (7.7%), the Euglenophyta (14 taxa, 7.2%), the Pyrrhophyta (8 taxa, 4.1%), and the Cryptophyta (4 taxa, 2.1%).

Twenty-one taxa were considered dominant, here defined as those species that comprised more than 10 percent of one or more samples during the study (Table C-8). Twenty-two taxa were seen in more than 50 percent of the samples examined during the year (Table C-9).

Phytoplankton taxa and assemblages seen in this study are similar to those seen previously in Hartwell Lake and in adjacent areas. Hern et al (1977) reported 73 taxa from samples taken during three seasons in Hartwell Lake. Fifty-three of these taxa (73%) were enumerated in the current study. Dominant taxa reported by Hern et al (1977) were also dominants in the present study. Similarly, 11 out of 15 dominant phytoplankton taxa found during 1973 to 1976 in Lake Keowee, S.C. (Duke Power Co., 1977) were dominants in the current study (Table C-7).

Nygaard (1949) stated that the presence and number of certain algal groups in an aquatic system were indicative of the trophic status of that system. He proposed several indices that could be used as a quantitative measure of trophic state. Hern et al (1977), using Nygaard's indices, classified Hartwell Lake as eutrophic. Their assessment of Hartwell Lake was based on the enumeration of single depth-composited samples taken in June, September and November of 1973. The location of these samples was not indicated in their report.

Nygaard's Compound Index was used to compute the trophic state of the lake based on the phytoplankton samples taken in the current study:

$$\text{Compound Index} = \frac{\text{Number of taxa of Cyanophyta + Chlorococcales + Centric diatoms + Euglena}}{\text{Number of taxa of Desmideae}}$$

TABLE C-7

Correlation Coefficients* (r^2) Between Chlorophyll *a* and Cell Counts for Each Depth-Composited Sample

Season	r^2	n
Winter	.88	18
Spring	.84	18
Early Summer	.92	17
Late Summer	.72	18
Autumn	.90	18
Overall	.73	89

*calculated from least-squares linear regression analysis

TABLE C-8

Dominant Taxa of Phytoplankton Enumerated From Hartwell Lake in 1981

(Defined as those taxa comprising greater than 10 percent of the total cells in one or more samples)

Cyanophyta

Anabaena circinalis
A. confervoides
Anabaena spp.
Anacystis incerta
A. montana
Lyngbya subtilis

Chlorophyta

Ankistrodesmus falcatus
A. falcatus v. acicularis
A. nannoselene

Cryptophyta

Cryptomonas sp. 1

Chrysophyta

Mallomonas eliptica
M. majorensis
Ochromonas sp.

Bacillariophyta

Cyclotella stelligera
Melosira ambigua
M. granulata v. angustissima
M. italica v. apigena
Nitzschia acicularis
Tabellaria fenestrata

Pyrrhophyta

Peridinium aciculiferum

TABLE C-9

Taxa of phytoplankton found in more than 50 percent of all samples enumerated.

Cyanophyta

Anacystis incerta
A. montana
Dactylococcopsis musicola

Chlorophyta

Ankistrodesmus falcatus
A. falcatus v. acicularis
A. nannoselene
Closteriopsis longissima
Golenkinia radiata
Scenedesmus bijuga

Cryptophyta

Cryptomonas ovata
Cryptomonas sp. 1
Cryptomonas sp. 2

Chrysophyta

Ochramonas sp.

Bacillariophyta

Cyclotella stelligera
Melosira granulata v. angustissima
M. italica v. alpigena
Nitzschia acicularis
Rhizosolenia longiseta
Synedra filiformis
Tabellaria fenestrata

Pyrrhophyta

Gymnodinium sp.
Peridinium aciculiferum

An index of 0 to 1.0 indicates oligotrophic waters. Values above 1.2 are indicative of eutrophic waters. Generally, the desmids in Lake Hartwell were encountered infrequently and occurred in only 18 of 90 phytoplankton samples during the year. The index was not computed in samples where desmids were absent, as it would calculate to infinity. Values for the Compound Index ranged from 2.7 to 18. Thus, in all cases the indices indicated (by Nygaard's definition) that Hartwell Lake was eutrophic.

Periphyton

One hundred thirty-seven taxa of periphyton were identified during the study (Table C-10). They are listed by season and station with their concentrations in Appendices C-11 through C-13. Cell densities varied from 9.14 cells · mm^{-2} in February at Station 7 to 1.81 x 10^4 cells · mm^{-2} at Station 12 in October. Population densities were lowest in the winter and higher in summer in autumn. River stations generally had higher population densities than did the lake stations, and lake stations farthest from the dam had the lowest densities (Appendices C-11 through C-13).).

The *Bacillariophyta* were dominant at Stations 1, 3 and 9 at all seasons except in October-November at Station 3, where the Cyanophyta were dominant. Bluegreen algae were dominant at Stations 5 and 7 at all sampling times except in June at Station 7, where diatoms were dominant. Green algae were dominant in every sample enumerated at Station 12 (Appendices C-14 through C-16).

Although not always dominant, diatoms were the most diverse, contributing 66 or 48.2% of the taxa of periphyton identified and counted in this study. Pennate diatoms were generally more abundant than centric taxa. Green algae contributed 40 taxa (29.2%), followed by the Cyanophyta (17 taxa, 12.4%), the Euglenophyta (6 taxa, 4.4%), the Pyrrhophyta (4 taxa, 2.9%), the Chrysophyta (3 taxa, 2.2%), and the Cryptophyta with one species (0.7%).

The most ubiquitous species seen in the study was the diatom Achnanthes microcephala. It was found in every sample at all seasons and contributed frequently in excess of 50% of a total sample (Appendices C-11 through C-13). Eighteen other species comprised greater than 10% of the total cell density in one or more samples during the study (Tables C-11). Five species were found in 50% or more of the samples. These were the cyanophyte Anacystis montana and the diatoms Achnanthes microcephala, Anemoneis vitrea, Navicula notha and Synedra filiformis.

Periphyton densities showed predictable seasonal trends, with the lowest seen in the winter and the highest seen in summer and autumn. Similar findings were reported in Lake Keowee, SC in 1975 and 1976 (Duke Power Company, 1977). Although densities varied greatly between lake and stream stations, they were in the usual order of magnitude for mixotrophic to eutrophic aquatic systems (Hohn and Hellerman, 1963; Foerster and Schlichting, 1965; Stockner and Armstrong, 1971).

TABLE C-10

Taxa Of Periphyton Enumerated in Hartwell Lake in 1981

Division Cyanophyta

Agmenellum aquadraduplicatum
Anabaena sp. 1
Anabaena sp. 2
Anabaena sp. 3
Anacystis incerta
Anacystis montana
Chroococcus limneticus
Coelosphaerium kuetzingianum
Dactylococcopsis raphidiodes
Lyngbya martensiana
Lyngbya sp. 1
Oscillatoria geminata
Oscillatoria limosa
Oscillatoria sp. 1
Oscillatoria sp. 2
Spirulina major
Spirulina subsalsa

Division Chlorophyta

Ankistrodesmus falcatus
Ankistrodesmus falcatus v. acicularis
Ankistrodesmus falcatus v. tumidus
Bulbochaete sp. 1
Chaetophora sp. 1
Chaetosphaeridium globosum
Characium naeglii
Characium rostrum
Chodatella quadriseta
Cloniophora sp. 1
Closteriopsis longissima
Coleochaete sp. 1
Crucigenia tetrapedia
Gonatozygon aculeatum
Gymnogongrus sp. 1
Lauterborniella elegantissima
Mougeotia sp. 1
Mougeotia sp. 2
Oedogonium sp. 1
Oedogonium sp. 2
Pediastrum tetras
Pediastrum tetras f. evoluta
Pediastrum tetras v. tetraodon
Planktonema lauterbornii
Protoderma viride
Quadrigula closteroides
Scenedesmus acuminatus
Scenedesmus armatus
Scenedesmus armatus v. bicaudatus
Scenedesmus bijuga
Scenedesmus quadricauda
Scenedesmus spinosus
Spirogyra sp. 1
Spirogyra sp. 2
Stigeoclonium polymorphum
Stigeoclonium sp. 1
Tetraedron caudatum
Tetraedron sp. 1
Tetraedron trigonum
Ulothrix sp. 1

Division Cryptophyta

Cryptomonas ovata

Division Chrysophyta

Dinobryon calciforme
Stipiticoccus vasiformis
Vaucheria sp. 1

Division Bacillariophyta

Achnanthes exigua v. heterovalvata
Achnanthes microcephala
Achnanthes sp. 1
Anemoneis vitrea
Asterionella formosa v. gracillima
Cocconeis placentula v. euglypta
Cyclotella stelligera
Cymbella affinis
Cymbella lunata
Cymbella microcephala
Cymbella minuta
Cymbella sp. 1
Cymbella tumida
Desmogonium rabenhorstianum v. elongatum
Diploneis puella
Entomoneis ornata
Eunotia curvata
Eunotia flexuosa
Eunotia pectinalis v. minor
Eunotia serra
Fragilaria capucina
Fragilaria crotonensis
Fragilaria sp. 1
Gomphonema acuminatum
Gomphonema affine
Gomphonema augur
Gomphonema carolinense
Gomphonema constrictum v. cuneata
Gomphonema gracile
Gomphonema intricatum
Gomphonema parvulum
Gomphonema sp. 1
Gomphonema subclavatum
Gomphonema truncatum
Gomphonema truncatum v. capitatum
Gomphonema truncatum v. turgidum
Melosira granulata
Melosira granulata v. angustissima
Melosira italica
Melosira italica v. alpigena
Melosira varians
Navicula cuspidata
Navicula elginensis v. rostrata
Navicula notha
Navicula radiosa
Navicula sp. 1
Nitzschia acicularis
Nitzschia lorenziana
Nitzschia palea
Nitzschia sp. 1
Nitzschia sp. 2
Nitzschia sp. 3
Pinnularia abaujensis v. rostrata
Pinnularia biceps
Pinnularia sp. 1
Pinnularia sp. 2
Pinnularia sp. 3
Stauroneis sp. 1
Surirella ovalis
Surirella sp. 1
Synedra delicatissima
Synedra filiformis
Synedra rumpens v. scotia
Synedra sp. 1
Tabellaria fenestrata
Tabellaria flocculosa

Division Pyrrhophyta

Ceratium carolinianum cyst
Gymnodinium spp.
Peridinium aciculiferum
Peridinium wisconsinense

Division Euglenophyta

Euglena sp. 1
Lepocinclis longicauda
Phacus sp. 1
Trachelomonas sp. 1
Trachelomonas sp. 2
Trachelomonas sp. 3

TABLE C-11

Dominant taxa of periphyton enumerated in this study. (Those taxa comprising greater than 10 percent of the total cells in one or more samples).

Cyanophyta

Anabaena sp.
Anacystis montana
Lyngbya martensiana
Oscillatoria geminata
O. limosa
Oscillatoria sp. 1

Chlorophyta

Chaetophora sp. 1
Characium naeglii
C. pringsheimii
Mougeotia sp. 1
Planktonema lauterbornii
Stigeoclonium polymorphum

Bacillariophyta

Achnanthes microcephala
Anemoneis vitrea
Cymbella microcephala
Cymbella sp. 1
Gomphonema parvulum
Melosira granulata v. angustissima
Navicula notha

Highest densities were in areas of flowing water at stations 9 and 12. Station 9 receives the majority of its water from the hypolimnion of Lake Keowee, while station 12 receives similar water from Hartwell Lake. It would be expected that these sources would be rich in nutrients, particularly nitrogen and phosphorus, and that such enrichment could explain high periphyton densities. Nutrient data from the two stations are conflicting. Station 12 consistently had concentrations of nitrate and orthophosphate that were two to ten times higher than concentrations measured at lake periphyton stations. Station 9, however, had concentrations of these nutrients that were similar to and often identical to those found at periphyton stations in the lake (Appendices B-37 and B-41). Thus, while higher nutrient levels help explain high periphyton densities at station 12, an alternative explanation is necessary to explain the high densities seen at station 9.

It is common to find abundant periphyton densities in lotic systems and is generally accepted that the growth and development of periphyton communities is accelerated as a function of current velocity (Whitford, 1960; Whitford and Schumacher, 1964). The opportunities for an attached algal cell to encounter nutrients, even in nutrient-poor streams are increased because the nutrient medium (i.e. the stream) flows past the cell. In stagnant waters an attached alga can quickly deplete the nutrients from around its cell and its growth can become nutrient limited. Thus, it appears that the periphyton in Hartwell Lake may have been at least in part nutrient limited, because of low vertical and horizontal circulation of the water column, and that station 9, while relatively low in nutrients, was not nutrient limited because of high water circulation.

Although phytoplankton populations were often high at stations 5 and 7, the periphyton densities were consistently low. As the turbidity at these stations was high relative to the other lake stations, we conclude that the growth and development of their periphyton populations in addition to being partially nutrient limited were also light limited.

It was not surprising that diatoms dominated the periphyton at most stations. Primary colonists of newly immersed substrates, such as glass slides, are usually diatoms (Chamberlain, 1976) and they often dominate on all substrates in moderately productive aquatic ecosystems (Stockner and Armstrong, 1971; Wetzel, 1975; Bowker and Denny, 1978).

Station 12 was the only station dominated by the Chlorophyta -- and this during all seasons (Appendices C-14 through C-16). As green algae can generally tolerate higher nutrient concentrations than diatoms (Patrick and Reimer, 1966), it is reasonable to conclude that the periphyton community downstream from Hartwell Dam were influenced by and reflected the elevated levels of nutrients found in the tailrace waters.

The percent contributions of the various algal divisions seen in this study was basically similar to that reported from Lake Keowee (Duke Power Co., 1977). There it was found, as it was in the present study, that diatoms contributed the most cells, followed by the Chlorophyta, the Cyanophyta, then all other algal groups. Further, they like we found that Achnanthes microcephala was the most abundant and common species among the diatoms. They

also reported Anemoneis vitrea, Gomphonema parvulum, Tabellaria fenestrata, and species of Synedra being very common, as did we in the present study. We also found 28 out of 77 taxa in common with a study done by John J. Haines (1979 unpublished report) in the tailrace waters of Hartwell Dam in the vicinity of station 12. Except for the notable absence of species of Eunotia in most samples, the assemblages of the diatom species enumerated in the lake stations are similar to those associated with circumneutral, oligotrophic to mixotrophic lakes (Hutchinson, 1967).

While there is an ongoing debate over whether the periphyton communities that develop on glass slides accurately reflect and define those communities that are naturally found in a given aquatic ecosystem (Castenholtz, 1961; Foerster and Schlichting, 1965; Tippett, 1970; Stockner and Armstrong, 1971; Brown, 1976; Siver, 1977), the use of glass slides is remarkably reproducible from season to season and year to year, provided that major changes have not occurred in the system (Patrick, 1949; 1964). Thus, the continued monitoring of the periphyton communities in Hartwell Lake, its sources and its tailwaters, would provide a useful tool in documenting perturbations to this important aquatic system.

D. ZOOPLANKTON

Zooplankton data are presented in Tables D-1 through D-5, and Appendices D-1 through D-5. There was little variation between duplicate samples, indicating density estimates should be reliable. A total of 28 species were identified, including 13 rotifers, 10 cladocerans, 5 cyclopoid copepods and one calanoid copepod (Table D-1). Chaoborus sp., hydra, and ostracods were also collected but not identified to species. The number of species of rotifers was probably underestimated slightly owing to the difficulties encountered in identifying these animals.

The number of species found at each station varied seasonally (Table D-2). At station one through five and station seven, the fewest were found in February while at station six the fewest were found in April and at station eight in February and June. The greatest number of species was found at all stations in summer or fall; at station one, species number peaked in June and October and at station eight in October. There was no obvious spatial pattern to the variation in numbers of species among stations at any time during the study.

Total zooplankton densities varied both seasonally and spatially (Table D-3). At most of the stations, total abundance was lowest in either February or April or April and highest in eigher July or October. At station 4, however, total abundance was lowest in July and at station 5, it was lowest in February and July. Abundance was still highest in October at both sites. Within sampling intervals, total abundance was usually relatively low at stations 1, 2, 6, and 7 and relatively high at stations 3, 4, and 8. The July sample at station 2 was a notable exception in that the total abundance of zooplankton at this station was high compared with the other July samples.

Species fall into four classes with regard to seasonal and spatial distributions (Table D-4). With the exception of Alona costata, Chydorus sphaericus, Cyclops bicuspidatus thomasi, and Paracyclops fimbriatus poppei, all of the species occurring in February were found each time the lake was sampled and usually at more than 50% of the stations. A second assemblage was seasonally distributed. Keratella sp., Ploesoma sp., Ptygura sp., Trichocerca sp., and Leptodora kindtii were not collected in February but each was found in up to four other sampling intervals, occasionally at high densities and usually at most of the stations. Cyclops bicuspidatus thomasi was widely distributed in February and April, rare in June, not found in July and October. Ceriodaphnia quadrangula occurred at

TABLE D-1

Zooplankton Species List

Cnidaria
- Hydra

Rotifers
- *Asplanchna* sp.
- *Brachionus havanaensis*
- *Conochilus unicornis*
- *Kellicotia bostoniensis*
- *Keratella cochlearis*
- *Keratella* sp.
- *Lecane* sp.
- *Monostyla* sp.
- *Platyias patula*
- *Ploeosoma* sp.
- *Polyarthra* sp.
- *Ptygura* sp.
- *Trichocerca* sp.

Cladocera
- *Alona costata*
- *Bosmina longirostris*
- *Bosminopsis dietersi*
- *Ceriodaphnia quadrangula*
- *Chydorus sphaericus*
- *Daphnia parvula*
- *Diaphanosoma Brachyurum*
- *Holopedium amazonicum*
- *Leptodora kindtii*
- *Moina minuta*

Copepoda
- Calanoida
  - *Diaptomus mississippiensis*
  - copepodids
- Cyclopoida
  - *Cyclops bicuspidatus thomasi* adults
  - *Eucyclops agilis* adults
  - *Mesocyclops edax* adults
  - *Paracyclops fimbriatus poppei* adults
  - *Tropocyclops prasinus* adults
  - copepodids
  - nauplii

Ostracoda

Insecta
- *Chaoborus* sp.

TABLE D-2

Total Number of Species per Sample

Station	Feb.	April	June	July	October
1	9	13	16	14	15
2	8	15	16	18	18
3	9	14	15	20	-
4	9	14	19	15	19
5	11	11	15	16	15
6	11	10	17	20	19
7	11	13	11	16	15
8	9	12	9	18	20

TABLE D-3

Mean Total Zooplankton Densities (animal/liter)
at Each Station During Each Sampling Period

Station	Feb.	April	June	July	October
1	20	10	126	129	50
2	18	39	52	154	50
3	115	143	75	326	-
4	184	258	219	139	548
5	70	133	241	71	285
6	40	73	71	98	56
7	27	45	67	84	422
8	46	85	430	117	473

TABLE D-4.

The seasonally occurrence of each species at each station. Each block of five symbols displays the presence (+) or absence (0) of a given species at a given station in samples collected in February, April, June, July and October, respectively.

	1	2	3	4	5	6	7	8
Cnidaria								
Hydra	00000	00000	0000-	00+00	00000	00000	00000	00000
Rotifera								
Asplanchna sp.	00+0+	0++0+	0++0+	+++0+	+++++	0++++	0+0++	0++0+
Brachionus havanaensis	00000	00000	0000+	00000	00000	00000	00000	000+0
Conochilus unicornis	0+000	0++0+	0++++	0++++	0++++	0++++	0+0++	0+0++
Kellicotia bostoniensis	000+0	0+0++	0+0++	++00+	0000+	+00++	0000+	00000
Keratella cochlearis	+++++	+++++	+++++	+++++	+++++	+++++	+++++	+++++
Keratella sp.	000+0	000+0	000++	000++	000++	000++	000++	000++
Lecane sp.	0000+	00000	0000+	00000	00000	00000	0000+	00000
Monostyla sp.	00000	0000+	0000+	0+000	00000	0000+	00000	00000
Platyias patulas	00000	00000	0000+	000+0	000+0	00000	000+0	000+0
Ploesoma sp.	0000+	000++	000++	000++	000++	000++	000++	000++
Polyarthra sp.	+++++	+++++	+++++	+++++	+++++	+++++	+++++	+++++
Ptygura sp.	000++	000++	000++	000++	000++	000++	000+0	000++
Trichocerca sp.	00+++	0++++	0++++	0++++	0++++	00+++	000++	00+++
Cladocera								
Alona costata	0+000	000+0	0++++	00+0+	00+00	000+0	++000	0000+
Bosmina longirostris	+++++	+++++	+++++	+++++	+++++	+++++	+++++	+++++
Bosminopsis dietersi	00000	00000	0000+	00000	00000	00000	00000	000+0
Ceriodaphnia quadrangula	00+++	00+++	00+++	00+++	00+++	+0+++	000+0	000++
Chydorus sphaericus	+0+00	00++0	000++	00+00	0++00	+0000	++000	0+00+
Daphnia parvula	+++0+	+++++	+++++	+++0+	++000	+++++	+++0+	++0++
Diaphanosoma brachyurum	0++++	0++++	+++++	0++++	+++++	00+++	0+++0	00+++
Holopedium amazonicum	+++++	+++++	+++++	0++++	++++0	+++++	+++++	+++++
Leptodora kindtii	0++++	0++++	00+++	00+0+	0000+	00+++	00+++	0000+
Moina minuta	00000	00000	0000+	00000	00000	00000	00000	000+0
Copepoda								
Calanoida								
Diaptomus mississippiensis	+++++	+++++	+++++	+++++	++++0	+++++	++++0	+++++
Cyclopoida								
Cyclops bicuspidatus thomasi	++000	++000	+++0+	+0000	+0000	+++00	++000	0+000
Encyclops agilis	00000	00000	0000+	00+00	00000	00+00	00000	00000
Mesocyclops edax	00++0	00++0	000++	00000	+0+00	00+++	+0+00	+00++
Paracyclops fimbriatus poppei	00000	00000	0000+	00000	00000	00000	00000	++000
Tropocyclops prasinus	+++++	+++++	+++++	+++++	+0+++	+++++	+0+++	+++++
Ostracoda	0++00	0+00+	000+	0++0+	00+0+	00000	0+000	00000
Insecta								
Chaoborus sp.	00+00	00+00	00++	00++0	00++0	00++0	00+0+	0000+

one station in February and none in April but was found at nearly all stations in June, July and October. A third group occurred only at station 8; Bosminopsis dietersi, Moina minuta, and Brachionus havanaensis were collected there in July and Paracyclops fimbriatus poppei was identified there in June. Finally, Platyias patulus, Lecane sp., Monostyla sp., Eucyclops agilis, hydra, Chaoborus sp., and ostracods were found sporadically throughout the study. None of these species were ever common or widespread and there is little discernible temporal or spatial pattern to their distributions. All of them, except Chaoborus and the ostracods, are normally either littoral or benthic species, or species more typically found in small ponds. Their occurrence in the plankton, therefore, may be incidental. Densities of Chaoborus may have been underestimated because many species migrate to the bottom during the day (Roth 1968; von Ende 1979). No samples were taken at night when more species might have been in the water column but Chaoborus is probably still a relatively rare species in Lake Hartwell plankton.

Disregarding the sporadically occurring species, assemblages found at most stations are quite similar within sampling periods. This reflects the widespread distribution of most of the species found in the lake. Stations 5 and 8 depart from this pattern; the larger cladocerans and copepods were absent or very rare at these locations. Both stations are very shallow, suggesting a relationship between depth, or a correlate of depth, and the size distribution of plankton at these sites.

Within each sample, relative abundances varied by factors of 10^4 to 10^5. There were many more rare species than common ones and usually 50% or more of the organisms in a sample belonged to three or fewer species or life history stages (Table D-5). Rotifers were by far the most abundant organisms in most of the samples. They represented at least 40% of the organisms counted at stations one through seven in February, stations one, two, four and eight in April, stations three, six and eight in June, stations one through four and six through eight in July and at all stations in October. Samples in which rotifers totaled less than 40% of the organisms counted were usually dominated by copepod nauplii and cyclopoid copepodids. However, in the April samples from stations six and seven and the June sample from station four, Bosmina longirostris was the most abundant organism.

Although many species of rotifers were found in the lake, only a few were ever particularly abundant. Polyarthra sp. and Keratella cochlearis appear to be the most common and most widespread species of rotifers in the system. Both were found in nearly every sample. There is some evidence of a seasonal shift in their relative abundances. Polyarthra was the most abundant rotifer at five stations in February and at five in April while K. cochlearis was the most abundant rotifer at two stations in February, two in April, seven in June, two in July and six in October. Other rotifers were occasionally dominant, including Asplanchna at station five in April, Trichocerca at station five in June, Ptygura at station one, two, six and seven in July and Ploesoma at station five in July and station three in October, but Polyarthra and Keratella were still relatively abundant at these locations and times.

TABLE D-5.

The dominant species or life history stages in each sample and the percentage of all zooplankton in that sample that each represents. Only forms constituting >5% of the organisms in a sample are listed.

February	Station 1	2	3	4	5	6	7	8
Rotifera								
Asplanchna sp.	-	-	-	-	10.0	-	-	-
Keratella cochlearis	-	-	38.3	25.5	12.4	-	-	-
Polyarthra sp.	65.0	54.0	15.7	18.5	20.0	40.0	48.2	-
Cladocera								
Bosmina longirostris	11.5	13.9	-	-	-	22.8	16.3	-
Copepoda								
Cyclopoid copepodids	7.00	6.11	20.9	12.5	6.57	13.3	6.30	26.1
nauplii	12.5	20.0	20.9	34.8	45.7	21.3	22.6	67.4

April	1	2	3	4	5	6	7	8
Rotifera								
Asplanchna sp.	-	-	-	-	12.0	-	-	9.65
Conochilus sp.	-	-	-	-	-	-	-	6.47
Keratella cochlearis	-	5.90	16.1	34.1	-	-	-	12.9
Polyarthra sp.	51.0	46.2	11.9	11.6	8.27	30.1	24.4	21.2
Trichocerca sp.	-	5.90	-	-	-	-	-	-
Cladocera								
Bosmina longirostris	37.0	21.0	23.1	13.2	21.8	49.3	46.7	15.3
Copepoda								
Cyclopoid copepodids	-	-	9.10	8.14	12.0	7.53	8.40	6.35
nauplii	6.60	10.5	35.0	39.5	36.8	8.63	9.33	25.9

June	1	2	3	4	5	6	7	8
Rotifera								
Asplanchna sp.	-	-	8.00	-	-	-	-	22.6
Keratella cochlearis	13.5	25.0	21.3	9.59	5.39	46.5	13.6	32.1
Polyarthra sp.	8.70	10.2	-	-	-	9.70	7.91	-
Trichocerca sp.	-	-	12.3	7.76	10.8	-	-	-
Cladocera								
Bosmina longirostris	9.52	9.62	25.3	32.0	33.6	-	-	-
Diaphanosoma brachyurum	-	-	-	-	-	5.92	14.9	-
Holopedium amazonicum	-	-	-	-	-	5.55	-	-
Copepoda								
Tropocyclops prasinus	11.9	5.19	-	-	5.39	-	-	-
Cyclopoid copepodids	16.7	13.1	-	11.0	9.96	5.49	6.42	5.81
nauplii	29.4	26.9	20.0	26.9	26.6	15.5	20.9	11.6

July	1	2	3	4	5	6	7	8
Rotifera								
Keratella cochlearis	-	-	18.7	30.9	-	-	16.7	5.38
Keratella sp.	-	-	5.83	15.1	53.5	-	19.1	28.1
Ploesoma sp.	-	-	-	-	25.4	-	-	-
Polyarthra sp.	-	-	7.67	6.19	5.35	-	-	6.24
Ptygura sp.	79.8	64.3	10.7	10.1	-	72.5	31.0	-
Trichocerca sp.	-	-	-	-	-	-	9.64	-
Cladocera								
Bosmina longirostris	-	-	6.75	5.47	-	-	-	-
Diaphanosoma brachyurum	-	-	7.06	6.26	-	-	-	-
Copepoda								
Calanoid copepodids	-	9.09	11.4	-	-	-	-	-
Tropocyclops prasinus	-	-	6.44	-	-	-	-	-
nauplii	-	-	18.7	5.97	-	12.2	-	-

October	1	2	3	4	5	6	7	8
Rotifera								
Asplanchna sp.	-	-	-	-	-	-	13.0	-
Keratella cochlearis	50.0	42.0	-	67.0	35.4	21.4	58.5	55.4
Ploesma	11.6	12.8	-	-	37.5	10.5	9.00	22.4
Polyarthra sp.	10.0	14.8	-	17.9	14.4	14.3	8.50	11.0
Trichocerca sp.	13.4	12.0	-	5.29	-	6.43	-	-
Cladocera								
Bosmina longirostris	6.40	-	-	-	-	13.0	-	-
Copepoda								
nauplii	5.40	5.80	-	5.47	-	23.2	-	-

Among the crustaceans, copepods were usually the most abundant forms, mainly because nauplii and cyclopoid copepodids were relatively abundant. Except at station one in July and October and station six in October, cyclopoid copepodids and adults were more abundant than were calanoid copepodids and adults. With regard to adults, Tropocyclops prasinus was the most abundant cyclopoid in most of the samples. However, Cyclops bicuspidatus thomasi was the most abundant cyclopoid at stations three, four, five and seven in February and at stations one, three, six and seven in April. Mesocyclops edax was the most abundant cyclopoid at station seven in June, station one in July and station eight in October. As noted earlier, Cyclops and Mesocyclops may occur seasonally; Cyclops was found at most stations in February and April but was absent in June, July and October while Mesocyclops occurred sporadically throughout the study but was most widespread in June and July. Tropocyclops was found in all of the samples except those collected in April from stations five and seven.

Among the cladocerans, Bosmina longirostris was usually the most abundant species, accounting for well over 50% of the cladocerans at all stations in February and April, at stations one through five and station eight in June, at stations one, three, four, five and eight in July and at stations one, two, and five through eight in October. Diaphanosoma brachyurum was the numerically dominant cladoceran at stations six and seven in June, at stations one through four, six and seven in July and at station two in October. Bosminopsis dietersi was the dominant cladoceran at station eight in July and Ceriodaphnia quadrangula was the dominant cladoceran at station four in October. However, even when other cladocerans were numerically dominant, Bosmina was still relatively abundant.

The zooplankton community of Lake Hartwell showed some notable differences from the community in Lake Keowee, located just upstream from Lake Hartwell on the Keowee River (Duke Power Company, 1977). Maximum and minimum total zooplankton densities were greater in Lake Hartwell than in Lake Keowee. Maximum densities in Lake Keowee were 80 to 120 animals per liter at most sample sites whereas maximum densities greater than 200 animals per liter were recorded at five stations and maximum densities of 120 to 200 animals per liter were found at the other three stations in Lake Hartwell. Minimum densities in Lake Keowee were generally less than 10 animals per liter while those in Lake Hartwell were greater than 20 animals per liter. The same seasonal patterns of total abundance were observed in both systems.

The dominance patterns among the zooplankton also differed somewhat between the lakes in that copepods were more frequently the most abundant group in Lake Keowee than in Lake Hartwell. However, cladocerans were generally the rarest of the three major groups in both systems. Tropocyclops prasinus was the most abundant cyclopoid copepod and Diaptomus mississippiensis was the only calanoid copepod in both systems. Among the cladocerans, the same genera but different species were dominant in the

two systems. Bosmina coregoni, Diaphanosoma leuchtenbergianum and Holopedium gibberum were the most abundant forms in Lake Keowee while Bosmina longirostris, Diaphanosoma brachyurum and Holopedium amazonicum were the most abundant forms in Lake Hartwell. Among the rotifers, the same species dominated both systems except that Gastropus stylifer and Collotheca spp. were abundant in Lake Keowee but were not found in Lake Hartwell. The studies conducted in the two systems do not provide any information on the reasons for the differences between them.

Since most of the animals found in the plankton of Lake Hartwell were herbivores, the results of this portion of the study were compared with the results of the phytoplankton study to see if the seasonal or spatial patterns of variation in zooplankton densities were associated with changing food supplies. Total rotifer densities, total cladoceran densities and total copepod densities were compared with phytoplankton densities, chlorophyl concentrations and phaeophyton concentrations. Correlation coefficients were obtained for variation among stations within times and among times within stations.

Of the 45 correlation coefficients for variation among stations within times, only two were significant ($p < .05$). In June, total rotifer density was correlated with both chlorophyl concentration and phytoplankton density. The phytoplankton variables tend to be correlated with each other (discussed in the phytoplankton section of this report) so it is not surprising to find that a zooplankton variable which is correlated with one of them is also correlated with another.

In the June samples, rotifer density, phytoplankton density and chlorophyl concentration were extremely high at station eight while values for the other stations were clustered at much lower levels. This departure of a single station from the others appears to be responsible for the strength of the correlations.

Of the 72 correlation coefficients for variation among times within stations, only two were significant. At station one, rotifer density was correlated with phytoplankton density and at station two copepod density was correlated with phaeophyton concentration.

The significant correlations for variation among stations within times and among times within stations must be interpreted with a great deal of caution. Chance alone should produce approximately two significant correlations ($p < .05$) in the first group and approximately three or four in the second group. Thus it is unlikely that the significant correlations contain much biological information.

In general then, the phytoplankton variables explain little of the variation in rotifer, cladoceran or copepod density. That is not to say that food is unimportant in the population dynamics of these groups (c.f. Hall 1964; Brambilla 1980). Rather, it is likely that the phytoplankton variables do not provide sufficiently precise information on the food available to zooplankton. For example, small species cannot ingest large cells or colonies (e.g. Burns 1968), so variation in the phytoplankton

size spectrum among station or times would interfere with the correlations between phytoplankton variables and zooplankton density. In addition, no information is available on the relative nutritional value of different species as food for herbivorous zooplankton. Change in food quality, caused by variation in the species composition of phytoplankton, can alter zooplankton reproductive parameters drastically (Arnold 1971; Schwartz and Ballinger 1980). Finally, changes in variables other than food supply can strongly affect zooplankton dynamics. For example, seasonal and spatial variation in predation is responsible for varying mortality rates in many systems (Hall 1964; Kerfoot 1975). Thus, varying predation intensity may contribute to change in zooplankton abundance and could obscure correlations between zooplankton density and phytoplankton variables. Without any information on zooplankton mortality rates this issue remains unresolved.

The zooplankton community in Lake Hartwell is, in many respects, similar to other communities which are shaped by size-selective fish predation (Brooks and Dodson 1965; Lynch 1979). Most of the species found in the lake are small. The large species of copepods found in Lake Hartwell are relatively rare and are considerably smaller than close relatives found in systems lacking planktivorous vertebrates. With the exception of Leptodora, the same is true for cladocerans. Leptodora is virtually transparent, which is probably an adaptation for avoidance to visually searching predators such as planktivorous fish (Kerfoot 1980). With no information on the food habits of fish in this system, it still seems probable that this community is shaped by size-selective predation.

MACROBENTHIC INVERTEBRATES

Natural Substrates - Densities and biomasses of all taxa for each date, station and sample are shown in Appendices E-1 and E-2. Table E-1 lists all species collected during the study with both the PONAR and Hester-Dendy samplers. The findings are summarized as densities of major taxa per station during each season in Table E-2 and as % composition in Table E-3. Total densities of organisms per station per season are shown in Table E-4. Biomasses of major taxa are summarized as g/m^2 and % composition in Table E-5 and E-6, respectively. Seasonal biomass totals for each station are shown in Table E-7.

The lake station located behind the dam, Station 1, was dominated by oligochaetes at all seasons - 49, 91 and 76% of total densities in April, June and November, respectively. Tubificidae were the most abundant oligiochaetes at Station 1 and were always found in greater densities in the deep-water site than in either the shallow- or mid-water sites (see Appendix E-1). Minute (.5 - 1 mm) juvenile bivalves were abundant at this station in the Spring (33% of total organisms) and Fall (15%). The very small size of these bivalves precluded identifying them to the species level; however, their great abundance suggests that they are juveniles of a commonly occuring species, perhaps Corbicula manilensis. They have been identified here only as juvenile Corbiculacea, a superfamily which includes both the Corbiculidae and the Sphaeriidae. Unlike the oligiochaetes, bivalves were more abundant in the littoral zone at Station 1.

In the spring mollusk were the biomass dominates (90% of total biomass) owing to the presence of a few large individuals of Corbicula manilensis (shell-less weights used). During June and November oligochaetes were the biomass dominates, 62 and 51% respectively.

Insects were low in abundance at Station 1 throughout the study, never accounting for more than 10% of the total numbers or 3% of the total biomass. Crustaceans were likewise rare at this station, most of those found being harpacticoid copepods, a taxa which is poorly sampled with the sieve size employed in this study.

Sediment grain sizes differed little between the different depth zone at Station 1 with the fine sand fraction (0.250-0.125 mm) comprising roughly 40% by weight at each depth (Appendix F-1). The occurrence of bivalves and oligochaetes in largely separate depth regions is, therefore, apparently not in response to sediment differences and may be a reflection of a greater tolerance to the low oxygen conditions of the deep-water by the oligochaetes.

At Station 3, the mouth of the Seneca River, April samples were dominated by the culicid larva Chaoborus sp. (32% of total organisms), juvenile Corbiculacea (32%) and tubificid oligochaetes (23%). At the same time a few individuals of the bivalve Corbicula manilensis accounted for 89% of the total biomass at the station. During the Spring 87% of the Chaoborus sp.

TABLE E-1

SPECIES LIST

Taxon	Ponar	Hester-Dendy
Cnidaria		
Hydra americana	+	+
Turbellaria	+	+
Nematoda	+	+
Ectoprocta		
Pectinella magnifica	+	+
Mollusca		
Gastropoda		
Ferrissia rivularis	+	+
Lymnaea columella		+
Physa sp.	+	
Bivalvia		
Corbicula manilensis	+	
Juvenile Corbiculacea	+	+
Musculium sp.	+	
Annelida		
Oligochaeta		
Naididae		
Chaetogaster diastophus	+	
C. setosa		+
Allonias pectinata	+	
Pristina obsorni	+	
P. brevisita	+	+
P. leidyi	+	
P. aequista		+
P. longesita		+
P. sp.	+	
Stylaria lacustris	+	+
Nais variabilis	+	+
Paranais sp.	+	
Tubificidae		
Branchiura sowerbyi	+	
Limnodrilus hoffmeisteri	+	
Tubifex tubifex	+	
Tubificidae sp.	+	
Lumbriculidae	+	+
Enchytraedidae	+	+
Arthropoda		
Crustacea		
Ostrocoda		
Lymnocethere sp.	+	
Cladocera		
Sida crystallina	+	
Chydorus sphaericus	+	
Alona guttata	+	
A. quadrangularis	+	
A. affinis	+	
A. costata	+	
Leydigia acamthocercoides	+	
Ilyocryptus spinifer	+	

	Ponar	Hester-Dendy
Amphipoda		
Hyalella azteca	+	+
Copepoda		
Cyclopoida	+	+
Harpacticoida	+	+
Decapoda		
Palaemonetes paludosus	+	+
Procambarus spinijer		+
Arachnoidea		
Hydrocarnia	+	+
Insecta		
Odonata		
Nehallenia sp.		+
Plathemis lydia	+	
Gomphus sp.	+	
Gomphidae sp.	+	
Cordulegaster sp.		+
Ephemeroptera		
Ephemerella invaira	+	+
E. sp.	+	+
Hexagenia sp.	+	+
Heterocloeon sp.	+	
Pseudocloeon sp.	+	
Stenonema rubrum	+	
Stenacron interpunctatum		+
Plecoptera		
Pteronarcys sp.		+
Trichoptera		
Polycentropus sp.		+
Neuroclipsis sp.	+	+
Cheumatophsyche sp.	+	+
Heliopsyche sp.	+	
Hydropsyche sp.	+	
Ochrotrichia sp.	+	
Hydroptilidae sp.	+	
Megaloptera		
Sialis sp.	+	
Coleoptera		
Dubiraphia sp.		+
Diptera		
Stratiomyiidae		
Odontomyia sp.		+
Sciomyzidae		
Dictya sp.	+	
Ceratopogonidae		
Ceratoponinae	+	
Culicidae		
Chaoborus sp.	+	
Tipulidae		
Tipula sp.	+	
Antocha sp.	+	
Tipulidae sp. (pupae)	+	+

	Ponar	Hester-Dendy
Chironomidae		
Alabesmyia mallochi	+	
A. sp.	+	+
Procladius sp.	+	+
Conchapelopia sp.	+	+
Coelotanypus tricolor	+	
C. sp.		
Tanypus sp.	+	
Eukiefferiella sp.	+	
Chironomus sp.	+	+
Dricotendipes nervosus	+	+
D. neomodestus	+	+
D. lobus	+	
D. sp.		+
Glyptotendipes sp.	+	+
Goeldichironomus holoprasinus	+	
Cricotopus sp.	+	+
Einfeldia sp.		+
Cryptochironomus fulvus	+	
C. sp.	+	
Tribelos fusicornis		+
T. sp.	+	
Polypedium fallax	+	
P. convictum		+
P. illinoense	+	
Brillia sp.	+	
Psectrocladius A	+	+
Orthocladius sp.	+	+
Cardiocladius sp.	+	
Trichocladius sp.		+
Cryptotendipes sp.	+	
Paralouterbormiella sp.	+	
Microspectra sp.	+	
Rheotanytarus sp. A	+	+
R. sp. B	+	+
R. sp. C		+
Thienmanneilla sp.		+
Potthatia langimanus		+
Chironomini sp.	+	
Pentaneurini sp.		+
Chironomidae (pupae)	+	

TABLE E-2

Ponar Densities (#/m^2)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	667	286	1670	163	120	0
Oligochaeta	999	209	859	137	0	807
Crustacea	210	0	333	0	3	510
Insecta						
Chironomidae	160	106	473	150	10	7429
non-chironomids	9	287	316	270	6	141
Others	0	0	0	10	3	57
Total	2045	888	3654	730	142	8944

B - June

Taxon	Station 1	3	5	7	9*	12
Mollusca	20	248	0	97	380	60
Oligochaeta	649	1248	3777	290	0	1413
Crustacea	10	5	13	0	0	43
Insecta						
Chironomidae	32	155	3198	20	0	486
non-chironomids	3	40	1393	564	0	96
Others	0	5	43	0	0	0
Total	714	1701	8424	971	380	2098

C - November

Taxon	Station 1	3	5	7	9**	12
Mollusca	203	1610	21	123	0	45
Oligochaeta	1020	657	390	360	0	4090
Crustacea	7	0	13	3	0	290
Insecta						
Chironomidae	60	336	277	130	0	150
non-chironomids	50	786	240	1026	0	110
Others	0	0	0	0	0	10
Total	1340	3389	941	1642	0	4695

* Shallow and deep samples only
** Mid-depth sample only

TABLE E-3

Ponar Densities (% Composition)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	32.6	32.2	45.7	22.3	80.5	0
Oligochaeta	48.9	23.5	23.5	18.8	0	9.0
Crustacea	10.3	0	9.1	0	2.0	5.7
Insecta						
Chironomidae	7.8	11.9	13.0	20.5	6.7	83.1
non-chironomids	0.4	32.3	8.7	37.0	4.0	1.6
Others	0	0	0	1.3	2.0	0.6

B - June

Taxon	Station 1	3	5	7	9*	12
Mollusca	2.8	14.6	0	10.0	100	2.9
Oligochaeta	90.9	73.4	44.8	29.9	0	67.3
Crustacea	1.4	0.3	0.2	0	0	2.0
Insecta						
Chironomidae	4.5	9.1	38.0	2.1	0	23.2
non-chironomids	0.4	2.4	16.5	58.1	0	4.6
Others	0	0.3	0.5	0	0	0

C - November

Taxon	Station 1	3	5	7	9**	12
Mollusca	15.1	47.5	2.2	7.5	0	1.0
Oligochaeta	76.1	19.4	41.4	21.9	0	87.?
Crustacea	0.5	0	1.4	0.2	0	6.2
Insecta						
Chironomidae	4.5	9.9	29.4	7.9	0	3.2
non-chironomids	3.7	23.2	25.5	62.5	0	2.3
Others	0	0	0	0	0	0.2

* Shallow and deep samples only
** Mid-depth sample only

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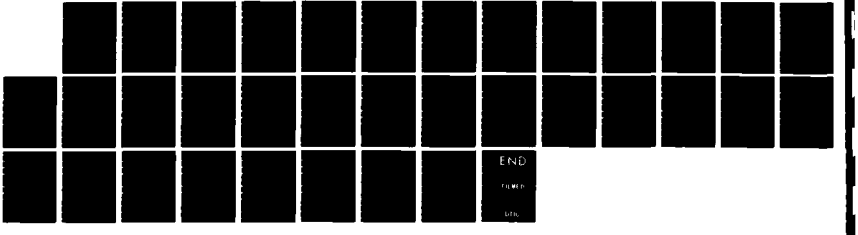

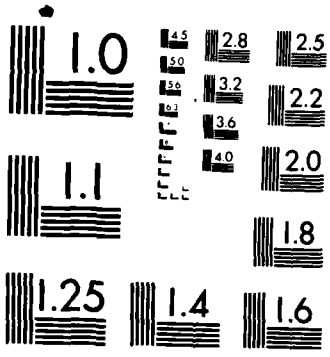

TABLE E- 4

Total Ponar Densities

(#/m^2)

Station	Spring	Summer	Fall
1	2045	714	1340
3	888	1701	3389
5	3654	8424	941
7	730	971	1642
9	142	380*	0**
12	8944	2098	4695

* Shallow and deep samples only
** Mid-depth sample only

TABLE E-5

Ponar Biomass (g/m^2)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	11.60	10.97	1.21	0.08	0.87	0
Oligochaeta	0.97	0.55	0.89	0.08	0	18.79
Crustacea	0	0	0	0	0	0.527
Insecta						
Chironomidae	0.14	0.08	0.38	0.13	0.01	5.92
non-chironomids	0.21	0.64	0.57	0.34	0.02	0.642
Others	0	0	0	0	0	0
Total	12.92	12.24	3.05	0.63	0.89	25.88

B - June

Taxon	Station 1	3	5	7	9 *	12
Mollusca	6.20	20.38	0	1.87	0.90	1.77
Oligochaeta	10.14	1.75	4.46	0.11	0	3.70
Crustacea	0	0	0	0	0	0.90
Insecta						
Chironomidae	0.08	0.11	3.00	0.06	0	0.37
non-chironomids	0.01	0.06	1.80	0.56	0	0.40
Others	0	0	0.90	0	0	0
Total	16.43	22.30	9.35	2.60	0.90	6.78

C - Novembe

Taxon	Station 1	3	5	7	9 **	12
Mollusca	1.23	2.49	0.68	0.48	0	1.68
Oligochaeta	1.33	0.85	0.68	0.47	0	5.26
Crustacea	0	0	0	0	0	0.06
Insecta						
Chironomidae	0.04	0.25	0.22	0.10	0	0.12
non-chironomids	0.03	0.43	0.35	0.76	0	5.58
Others	0	0	0	0	0	0.02
Total	2.63	4.02	1.93	1.81	0	12.70

* Shallow and deep samples only
** Mid-depth sample only

TABLE E-6

Ponar Biomass (% Composition)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	89.8	89.6	39.7	12.7	96.7	0
Oligochaeta	7.5	4.5	29.1	12.7	0	72.6
Crustacea	0	0	0	0	0	2.0
Insecta						
Chironomidae	1.1	0.7	12.5	20.6	1.1	22.9
non-chironomids	1.6	5.2	18.7	54.0	2.2	2.5
Others	0	0	0	0	0	0

B - June

Taxon	Station 1	3	5	7	9 *	12
Mollusca	37.7	91.4	0	71.9	100	26.1
Oligochaeta	61.7	7.8	47.7	4.2	0	54.6
Crustacea	0	0	0	0	0	13.3
Insecta						
Chironomidae	0.5	0.5	32.1	2.3	0	5.5
non-chironomids	<0.1	0.3	19.3	21.5	0	0.6
Others	0	0	1.0	0	0	0

C - November

Taxon	Station 1	3	5	7	9 **	12
Mollusca	46.8	61.9	35.2	26.5	0	13.2
Oligochaeta	50.6	21.1	35.2	26.0	0	4.14
Crustacea	0	0	0	0	0	0.5
Insecta						
Chironomidae	1.5	6.2	11.4	5.5	0	0.9
non-chironomids	1.1	10.7	18.1	42.0	0	43.9
Others	0	0	0	0	0	0.2

* Shallow and deep samples only
** Mid-depth sample only

TABLE E- 7

Total Ponar Biomass

(g/m^2)

Station	Spring	Summer	Fall
1	12.92	16.43	2.63
3	12.24	22.30	4.02
5	3.05	9.35	1.93
7	0.63	2.60	1.81
9	0.89	0.90*	0**
12	25.88	6.78	12.70

* Shallow and deep samples only
** Mid-depth sample only

were collected in the deep-water site and none in the littoral zone. Bivalves occurred in the shallow- and mid-depth samples only. Also, tubificids were found only in the littoral zone and 1% light level depths.

In June Chaoborus sp. abundance at Station 3 fell to below 1% of total organisms. Mollusk abundance and distribution with depth was unchanged, and again the presence of a few Corbicula manilensis ($25/m^2$) dominated the biomass (91% of total station biomass). Tubificid densities were increased nearly sixfold over April densities and accounted for 74% of the total number of organisms at Station 3. However, because of the small size of these worms they comprised only 8% of the station biomass at this time. A deep-depth sample was not obtained in June at Station 3, but 70% of the tubificids collected at that time were at the mid-depth site.

Tubificid densities decreased by approximately 50% in November at Station 3 ($675/m^2$), accounting for only 19% of the total fauna. Densities of juvenile Corbiculacae increased from $235/m^2$. Once again the presence of a few ($7/m^2$) Corbicula manilensis dominated the station biomass (61% of total). Chaoborus sp. densities were greatest at this station in the Fall. A station average of 786 individuals/m^2 Chaoborus sp. accounted for 23% of the total fauna; however, Chaoborus sp. were found exclusively at the mid-depth site where, at a density of $2340/m^2$, it comprised over 75% of the fauna at that depth. Owing to its small size Chaoborus sp. accounted for only 10% of Station 3 biomass in November.

Chironomid densities changed little at Station 3 throughout the study, ranging from 9-12% of the fauna. Most of the chironomids found were collected at the mid-depth site and the only chironomid found in deep-water, Chironomus sp., was at low densities ($30/m^2$).

Station 3 showed different trends in faunal composition from Station 1. At the lake station total faunal density was greater in April (a total of 2058 individuals/m^2) than either June or November (714 and 1300 individuals/m^2, respectively), while at the mouth of the Seneca the greatest density of benthic invertebrates was encountered in the Fall, when 3402 individuals/m^2 was the average total faunal density. Furthermore, at Station 1 the deep-water site always contained the greatest densities of organisms and at Station 3 the shallow- and mid-depth sites had greater total abundances than the deep site. The cause of these differences is not clear. Sediment grain sizes are similar at each station (Appendix F-1) and dissolved oxygen profiles were similar for both stations in June and November (Appendices B-9 and B-11, and B-17 and B-19, respectively).

Station 5, the cove site in the Seneca River, was similar to Stations 1 and 3 in April in that it was dominated by juvenile bivalves (45% of total organisms) and tubificids (23%). Both of these taxa were found largely in the littoral zone where they reach their greatest densities among all stations, over $4100/m^2$ and $1500/m^2$ in April for bivalves and tubificids, respectively. Chironomids comprised 13% of the fauna in the cove in April. The chironomid species found in the cove at that time were the same as those collected at the other above-dam stations (see Appendix E-1).

In June bivalves were absent in the cove samples. Tubificid densities increased significantly at Station 5 in the summer, ad they did at Station 3. Unlike Stations 1 and 3 in which tubificid were most abundant in deep- or mid-water, the cove station had the greatest density of tubificids (over 8000/m^2) in the littoral zone. Chironomids were more abundant at Station 5 in the summer (3198 individuals/m^2) than at any other station, and they accounted for 38% of the total fauna and 32% of the total macrobenthic biomass. Chironomid diversity was also high in the cove at this time, with 19 species being collected (Appendix E-1). The dipteran Chaoborus sp. was abundant at Station 5 in June, reaching its greatest densities observed throughout the study for any station in the deep area of the cove where densities exceeded 2100 individuals/m^2.

In the fall samples bivalves did not increase substantially at Station 5 as they did at Stations 1 and 3. Tubificid densities decreased nearly ten-fold between June and November in the cove, declining from an average of 3777 individuals/m^2 to 390/m^2. Likewise, chironomid and Chaoborus sp. densities fell to 277/m^2 and 230/m^2, respectively. As a result of these declines Station 5, which had the greatest densities of macroinvertebrates among all stations in the summer, had the lowest densities among all stations (excepting Station 9) in the fall (Table E-4).

Station 5 is unique among stations (excluding Station 9) in having its greatest organism density in the summer (Table E-4). This resulted from the high densities of tubificids, chironomids and Chaoborus sp., the latter two of which were not found in great abundance at any other station during the summer. The cause of these high densities in the cove in the summer is not known. Similarly, the cause of the decrease in bivalve abundance, which was observed at all lake stations (excluding Station 9), but which was most pronounced in the cove where denisties dropped to zero, is unknown. Physical and chemical parameters (water temperature, dissolved oxygen, sediment organics and metal concentrations) do not appear to explain either he high densities of chironomids and Chaoborus sp. or the absence of bivalves in the summer in the cove.

Station 7, the Tugaloo River station, differs from Stations 1, 3, and 5 in being dominated by Chaoborus sp. in all seasons sampled - 44% of total fauna in April, 57% in June, and 61% in November. This station also differed in that naidid oligochaetes were more abundant than tubificids in the spring samples (80 individuals/m^2 compared to 57/m^2). In the summer and fall, however, tubificids were the predominate oligochaetes at this station. The juvenile corbiculacea bivalve was present at the Tugoloo station, but at no time did it reach the high densities observed at Stations 1, 3 and 5; it ranged from 87-163 individuals/m^2. Both chironomid densities (maximum 150/m^2 in April) and number of chironomid species (maximum of 5 in November) were considerably less for Station 7 than for the cove station on the Seneca River (Station 5). Total station biomass for the Tugaloo site was relatively low (range 0.63 g/m^2 - 2.56 g/m^2), exceeding only Station 9 in April and June, and Stations 5 and 9 in November.

Sediment grain sizes at Station 7 were similar to those at Station 5, being predominantly medium and fine sands (0.250-0.450 mm) (Appendix F-1). Hence, substrate differences are not adequate to explain their different faunal compositions. Most water quality and sediment parameters (including organics and metals) at Station 7 showed little differences from Stations 1, 3, and 5 which might be interpreted as accounting for the different patterns of species abundance.

Station 9, located on the Seneca River approximately 1 kilometer downstream from Keowee Toxaway Dam, was subjected to extremely variable water levels and flow conditions. These conditions made some grab samples unattainable during certain periods of the study. During June, only the shallow and deep samples were obtained, while in November, only a mid-depth sample was retreived. Despite these missing samples, it is obvious that Station 9 low densities of macrobenthic invertebrates throughout the study (Table E-2). Juvenile Corbiculacea, the most abundant taxa (117 individuals/m^2), were most common in the mid-channel region of the station in April (Appendix E-1). Dipteran larvae (chironomids, Chaoborus sp., and tipulids) were present, but at low densities (16 individuals/m^2). In June, bivalves were the only taxa collected at Station 9. Juvenile Corbiculacea were collected in both the littoral and mid-channel samples (a mid-depth sample was not obtained in June), and a few (30/m^2) Musculium sp. were collected from the mid-channel (Appendix E-1). During November, low water levels caused the previous littoral zone at Station 9 to be exposed, while poor weather conditions prevented a mid-channel sample. As such, only a mid-depth sample was obtained at that time. No macrobenthic invertebrates were found in these collections (Table E-2C).

Sediment grain sizes at Station 9 were similar to those at other lake stations (Appendix F-1). Total organic concentration of the sediments at Station 9 was less than 1 mg/g compared to a range of 7-16 mg/g for the other lake stations (Appendix F-1). This low organic content is probably not the cause of the low faunal abundances at Station 9, rather both are likely consequences of scouring by high current velocities. Located below the Keowee Toxaway Dam, this site is subject to the periodic erosion of substrate, which presumably removes both benthic invertebrates and particulate organics.

Station 12, located approximately 3 kilometers downstream of Hartwell Dam, had the greatest total density (8944 animals/m^2), biomass (25.9 g/m^2) and number of species (20) of all stations in April (Appendices E-1 and E-2). Chironomids comprised 83% of the total fauna at this station in the spring (Table E-3). Of the 10 species of chironomids collected at this site in April, Cardiocladius sp. was the most abundant (58% of the total). None of these chironomids were found at the above-dam stations (Appendix E-1). Lumbriculid oligochaetes dominated the river macrobenthic biomass at that time (73% of total) (Table E-6;Appendix E-2). Mollusks were absent from Station 12 samples in April. Amphipods and mayflies were found in moderate abundances (263/m^2 and 124/m^2, respectively) (Appendix E-1). The sampling method employed probably underestimated the abundances of Ephemeroptera, Trichoptera, Odonata, and Plecoptera at this sample site.

By June, the chironomid species which had dominated the river station in April had emerged and 4 different chironomid species were present, the

most abundant of which was Cricotopus sp. Chironomid densities during the summer were much lower than in the spring at this station (7429/m^2 in the spring; 486/m^2 in the summer) and they comprised only 23% of the station fauna. Tubificid oligochaetes were abundant at station 12 during June, accounting for 67% of the total number of organisms and 55% of the total biomass. Total river density of macrobenthic invertebrates was more than four-fold lower in June than in April (2098/m^2 versus 8944/m^2). This is very likely the consequence of normal life-history patterns of many chironomid species which emerged during this interval.

In November, Station 12 again had the highest densities (4695 animals/m^2) and biomass (12.7 g/m^2) of all stations (Tables E-2C and E-5C, respectively). Tubificids comprised 87% of the total fauna and 41% of the total biomass at the station. A few large Odanta (10/m^2) accounted for over 40% of the station biomass (Appendix E-2). Chironomid densities remained low in November with only two species present at this station.

Artificial Substrates - The Hester-Dendy artificial substrate samplers collected benthic and littoral macroinvertebrates which comprise a "drift" community. Animals which are relatively stationary, poor swimmers or too heavy to be resuspended and transported by currents were rarely collected by this method. Such animals include bivalves, many chironomid species and culicids which were abundant in the PONAR samples (Appendix E-1) but rare or absent from the Hester-Dendy samples (Appendix E-3).

The drift community at Station 1 was dominated in April by the Cladoceran Sida crystallina which comprised 96% of the total organisms (Table E-9; Appendix E-3) and 78% of the total biomass (Table E-12; Appendix E-4). Deep-water samplers were not retrieved at Station 1 in April, but the littoral zone and the 1% light zone samplers contained similar densities of organisms. S. crystallina densities decreased from 567/m^2 in April to 3/m^2 in June at Station 1. During June, the naidid oligochaetes Nais variabilis and Pristina brevisita and the gastropods Terreissia rivularis and Lymnaea columella were the dominant taxa. The oligochaetes accounted for 41% of the total organisms and 8% of the total biomass, while the gastropods comprised 47% of the total organisms and 88% of the total biomass. Gastropod biomasses, however, include shell weight and therefore overestimate the actual biomass of this taxa. S. crystallina was again abundant at Station 1 (66% of total individuals and 13 % of total biomass) in November (Tables E-9 and E-12, respectively). At that time S. crystallina was very concentrated at the mid-depth location, where densities averaged over 1800/m^2 (Appendix E-3). N. variabilis remained abundant in the fall (15% of total fauna) but the other oligochaete collected in June, P. brevisita, was not collected in November. Gastropods, abundant in the summer, were not found at Station 1 in the fall.

April Hester-Dendy samplers at Station 3 were colonized only by crustaceans and a few nematodes (Table E-8A). The cladoceran Sida crystallina accounted for 95% of the organisms collected and nearly 100% of the biomass Tables E-9A, E-12A; Appendix E-3). Summer samples from the same station had no S. crystallina, but were instead dominated by the hydroid Hydra americana, the oligochaete Nais variabilis, and the chironomid Dricotendipes nervosus which comprised 23, 38, and 25% of the fauna, respectively (Tables E-8B, E-9B, E-11B, and E-12B; Appendices E-3 and E-4). H americana was most

TABLE E-8

Hester-Dendy Densities (#/m^2)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	3	0	0	0	0	0
Oligochaeta	7	0	237	72	0	18
Crustacea	630	1390	336	106	0	0
Insecta						
Chironomidae	3	0	4	2	0	430
non-chironomids	3	0	0	0	0	6
Others	8	7	6	0	0	0
Total	654	1397	583	180	0	454

B - June

Taxon	Station 1	3	5	7	9 *	12
Mollusca	423	25	0	0	-	20
Oligochaeta	368	1919	1309	3845	-	10,595
Crustacea	6	93	13	75	-	108
Insecta						
Chironomidae	82	1359	772	567	-	2747
non-chironomids	23	464	254	0	-	187
Others	0	1133	33	14	-	10
Total	902	4993	2381	4501	-	13,667

C - November

Taxon	Station 1	3	5	7	9 **	12
Mollusca	9	0	0	0	0	0
Oligochaeta	176	172	67	2250	184	601
Crustacea	797	1569	2910	2905	24	88
Insecta						
Chironomidae	146	1398	2142	949	79	2140
non-chironomids	67	332	319	25	0	41
Others	9	28	0	68	0	3
Total	1204	3499	5438	6197	287	2873

* Not sampled
** Shallow and deep samples only

TABLE E-9

Hester-Dendy Densities (% Composition)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	0.5	0	0	0	0	0
Oligochaeta	1.1	0	40.9	40.0	0	4.0
Crustacea	96.3	99.5	58.0	58.9	0	0
Insecta						
Chironomidae	0.5	0	0.4	1.1	0	94.7
non-chironomids	0.5	0	0	0	0	1.3
Others	1.1	0.5	0.7	0	0	0

B - June

Taxon	Station 1	3	5	7	9*	12
Mollusca	46.9	0.5	0	0	-	0.1
Oligochaeta	40.8	38.4	55.0	85.4	-	77.5
Crustacea	0.7	1.9	0.5	1.7	-	0.8
Insecta						
Chironomidae	9.1	27.2	42.4	12.6	-	20.1
non-chironomids	2.5	9.3	10.7	0	-	1.4
Others	0	22.7	1.4	0.3	-	<0.1

C - November

Taxon	Station 1	3	5	7	9**	12
Mollusca	0.7	0	0	0	0	0
Oligochaeta	14.6	4.9	1.2	36.3	64.1	20.9
Crustacea	66.2	44.8	53.4	46.9	8.4	3.1
Insecta						
Chironomidae	12.1	40.0	39.4	15.3	27.5	74.5
non-chironomids	5.6	9.5	5.9	0.4	0	1.4
Others	0.7	0.8	0	1.1	0	0.1

* Not sampled
** Shallow and deep samples only

TABLE E-10

Total Hester-Dendy Densities

(#/m^2)

Station	Spring	Summer	Fall
1	654	902	1204
3	1397	4993	3499
5	583	2381	5438
7	180	4501	6197
9	0	-*	287**
12	454	13667	2873

* Not sampled
** Shallow and deep samples only

TABLE E-11

Hester-Dendy Biomass (g/m^2)

A - April

Taxon	Station 1	3	5	7	9	12
Mollusca	0.02	0	0	0	0	0
Oligochaeta	<0.01	0	0.19	0.06	0	0
Crustacea	0.20	0.46	0.06	0.03	0	0
Insecta						
Chironomidae	<0.01	0	<0.01	<0.01	0	0.34
non-chironomids	0.02	0	0	0	0	0.05
Others	0.01	0	0.01	0	0	0
Total	0.26	0.46	0.25	0.09	0	0.41

B - June

Taxon	Station 1	3	5	7	9*	12
Mollusca	2.31	0.03	0	0	-	0.10
Oligochaeta	0.21	1.19	0.01	2.29	-	6.44
Crustacea	<0.01	0.04	0.01	0.01	-	0.02
Insecta						
Chironomidae	0.06	1.10	0.62	0.48	-	2.20
non-chironomids	0.06	1.74	0.97	0	-	0.73
Others	0	2.27	0.07	0.30	-	0.03
Total	2.65	6.36	2.45	3.10	-	9.52

C - November

Taxon	Station 1	3	5	7	9**	12
Mollusca	0.01	0	0	0	0	0.06
Oligochaeta	1.01	0.97	0.36	13.26	1.08	3.51
Crustacea	0.27	0.49	0.98	1.01	0.01	0.02
Insecta						
Chironomidae	0.12	1.12	1.72	0.76	0.06	1.71
non-chironomids	0.73	1.26	1.26	0.09	0	0.92
Others	0.02	0.06	0	0.18	0	0
Total	1.80	3.90	4.32	15.30	1.15	6.22

* Not sampled
** Shallow and deep samples only

TABLE E-12

Hester-Dendy Biomass (% Composition)

A - April

	Station					
Taxon	1	3	5	7	9	12
Mollusca	7.8	0	0	0	0	0
Oligochaeta	1.6	0	75.6	60	0	4.9
Crustacea	78.1	100	23.9	30	0	0
Insecta						
Chironomidae	0.8	0	<0.1	10	0	82.9
non-chironomids	7.8	0	0	0	0	12.2
Others	3.9	0	<0.1	0	0	0

B - June

	Station					
Taxon	1	3	5	7	9*	12
Mollusca	87.5	0.5	0	0	-	1.1
Oligochaeta	8.0	18.7	0.6	81.5	-	67.6
Crustacea	<.05	0.6	0.6	0.4	-	0.2
Insecta						
Chironomidae	2.3	17.3	36.9	17.1	-	23.1
non-chironomids	2.3	27.3	57.7	0	-	7.7
Others	0	35.6	4.2	1.1	-	0.3

C - November

	Station					
Taxon	1	3	5	7	9**	12
Mollusca	0.5	0	0	0	0	1.0
Oligochaeta	46.8	24.9	8.3	86.7	93.9	56.4
Crustacea	12.5	12.6	22.7	6.6	0.9	0.3
Insecta						
Chironomidae	5.6	28.7	39.8	5.0	5.9	27.5
non-chironomids	33.8	32.3	29.2	0.6	0	14.8
Others	0.9	1.5	0	1.2	0	0

* Not sampled
** Shallow and deep samples only

TABLE E-1 3

Total Hester-Dendy Biomass

(g/m^2)

Station	Spring	Summer	Fall
1	0.26	2.65	1.80
3	0.46	6.36	3.90
5	0.25	2.45	4.32
7	0.09	3.10	15.30
9	0	-*	1.15**
12	0.41	9.52	6.22

* Not sampled
** Shallow and deep samples only

abundant at the mid-depth (1% light level) site, N. variabilis was abundant at both the littoral and mid-depth sites, and D. nervosus was found at both depths but was more abundant at mid-depth. Deep water samplers were not retrieved in June from Station 3. Abundance patterns in the fall were similar to those at Station 1 (Tables E-8C and E-9C; Appendix E-3). Oligochaete densities declined to 5% of total fauna. Sida crystallina increased in density to over 1500/m^2 (44% of total fauna) and was more abundant at mid- and deep-water sites than in the littoral zone. Chironomid densities remained similar to those in the summer (over 1300/m^2 and 40% of all fauna). The trichopteran Neuroclipsis sp. comprised 32% of the biomass on the Hester-Dendy sampler at Station 3 in the fall (Table E-12C; Appendix E-4).

At Station 5, the cove on the Seneca River, Sida crystallina was the most abundant species in the April samples, as it was for Stations 1, 3, and 7 (Appendix E-3). However, unlike Stations 1 and 3, the cove had a significant number (237/m^2 and 41% of all Fauna) (Tables E-8A and E-9A) of naidid oligochaetes Pristina brevisita and Nais variabilis. These oligochaetes made up over 75% of the biomass at this station in the spring (Table E-12A). The patterns of species abundance in the cove through the summer and fall were similar to those observed at Stations 1 and 3. Sida crystallina declined in June to 0.5% of total fauna, while oligochaete and chironomid densities continued to increase (39% of all fauna) (Table E-9). As at Station 3, a substantial portion of Hester-Dendy biomass at Station 5 was made up by Neuroclipsis sp., with 58% in the summer and 29% in the fall (Table E-12).

Species abundances in the drift community at Station 7 in the Tugaloo River have a similar seasonal pattern to that observed at Stations 1, 3, and 5. In the spring, Sida crystallina dominated (59% of all fauna) but as at Station 5, a significant portion (40%) of the fauna is comprised of naidid oligochaetes (Table E-9). Cladoceran densities declined in the summer to 1.7% of all fauna, while oligochaete and chironomid densities increased (Table E-9B). In the fall, S. crystallina and chironomid densities increased, as they did at Stations 1, 3, and 5, but naidid densities remained high (2250 individuals/m^2) rather than declining as they did at the other stations (Table E-9C; Appendix E-3).

At Station 9 on the Seneca River, 9 Hester-Dendy samplers were deployed in the spring and all were collected in April. No animals were found on any of these plates. In June, Hester-Dendy samplers were placed in the field at Station 9, but all were washed away by high currents. In November Hester-Dendy samplers were retrieved from the littoral and mid-channel regions of Station 9. 64% of the fauna on these plates were Nais variabilis (184 animals/m^2), 27.5% were chironomids (12 species were found), and 8% were Sida crystallina (Table E-12C; Appendix E-3).

At the Savannah River station, Station 12, April Hester-Dendy samples were dominated (95% of all fauna) by a single species of chironomid, Cricotopus sp. (Appendix E-3). This species was collected at the same time in the PONAR samples (Appendix E-1), but it was not a dominant taxon. Also, during the spring, three species of naidid oligochaetes (Pristina brevisita, P. aequista and Nais variabilis) were collected on the Hester-Dendy samplers. None of these worms were present in the PONAR samples taken at the same time.

In June, chironomids were no longer the dominant taxa collected on the Hester-Dendy samplers at Station 12, representing only 20% of the total fauna (Table E-9B). Cricotopus sp. was still abundant (1200/m^2); however a total of eight species of chironomids were collected and Tribelos fusicornis was the most abundant (over 1300/m^2) (Appendix E-3). T. fusicornis was not collected in the June PONAR samples at this station (Appendix E-1). The most abundant taxa in June were naidid oligochaetes, principally Nais variabilis which averaged nearly 1000 individuals/m^2. N. variabilis was present but not abundant in the PONAR samples taken concurrently.

Nais variabilis densities at Station 12 declined in November to 539 individuals/m^2 and chironomid densities increased. Cricotopus sp. was again the most abundant chironomid, averaging 1974 animals/m^2 (Appendix E-3). Chironomids comprised 75% of the fauna collected on the Hester-Dendy samplers in November, but only three percent of the animals collected with the PONAR at the same time (Tables E-3C and E-9C).

The species collected by PONAR grab sampler in this study were largely the same as those reported for Hartwell Lake grab samples from 1973-1976 (Duke Power Company 1977). Differences in sample locations and sampling procedures make it impossible to determine whether the few differences observed between faunal composition in this study and the Duke Power study result from sampling differences or represent real temporal changes in species composition of the lake. The present study, by using the Hester-Dendy samplers, collected littoral cladocerans which were not sampled in the previous study.

Studies conducted by the U. S. Fish and Wildlife Service (1981) of Hartwell Lake's tailwaters included Hester-Dendy samples taken in 1979 near Station 12 of the present study. Species-level abundance data are not reported in the earlier report, but comparisons between major taxa reveal some similarities and differences between the two studies. In both studies, chironomids dominated (over 90% of the individuals) April samples. The total density of organisms was lower for April samples in the present study (454/m^2) than in the 1979 study (2848/m^2). Summer samples from Station 12 in the present study were collected in June while the 1979 summer samples were collected in late May and August. The late May samples from the previous study resembled the June samples of the current study in showing a decline of chironomid numbers and a sharp increase in oligochaete densities. Total densities of organisms during the early summer were greater in the present study (13,667/m^2) than in the earlier study (4,807/m^2), owing largely to greater densities of oligochaetes collected in the current study. November samples collected by the two studies differ in that chironomids returned to dominance at Station 12 in the present study, while the equivalent station of the 1979 study was dominated by oligochaetes and flatworms (Appendix B-2). The extent to which the differences observed in the two studies represent real temporal changes in the macrobenthic community downstream from Hartwell Dam cannot be assessed at present. Any discrepancies in the findings of the two studies may arise from differences in sample location, sampling date, or simply natural temporal fluctuations of the resident populations. Nonetheless, the general similarities between the fauna collected in 1979 and 1981 does indicate that the invertebrate community in this region of the Hartwell system has changed little during this time span.

The causes of the population fluctuations observed in this study are difficult to discern. Stations 1 and 3 were nearly anoxic at the deep sites in November and Station 5 water contained less than 1 mg/l of dissolved oxygen in June, but these conditions do not seem to have adversely affected the macrobenthos, which in some cases reaches its greatest densities at these low O_2 periods. Physical and chemical properties of the sediments do not show any seasonal trends which might cause the observed population changes.

During the late summer and fall of 1981, the southeastern United States experienced a draught which caused the water level of Hartwell Lake to fall approximately 12 feet between June and December (Figure A-1). The role which this decline in lake level may have played in the observed population fluctuations is unclear. Compounding the question on the effects of the declining lake level on macroinvertebrate populations is that of the falling lake level on sampling; as lake levels receded, the locations of the shallow and mid-water sample sites changed. The extent to which variations in observed community structure result from these changes in the location of the sites, rather than temporal variability, is not discernable from the data presented here.

It is likely that most of the observed seasonal variation in macrobenthic invertebrate populations was a result of life-history patterns and/or predation patterns. For instance, the disappearance of many chironomid species between April and June probably reflects the emergence of these species. The decreases in the cladoceran Sida crystallina between April and June may result from the production of ephipia or may reflect losses due to predation. Unfortunately, the cause of this and other population trends cannot be evaluated by the present study.

Between station differences in faunal composition and abundance exist, and only in some instances can the causes be evaluated from the present study. Station 1, located just above the dam, and Station 3, at the mouth of the Seneca River, had similar species compositions and seasonal patterns. The principal difference between the two stations was the presence of greater numbers of culicids and tricopterans at Station 3 and may result from the shallower depths at this station. Station 5 contained many of the same species found at Stations 1 and 3, but also contained a number of other species, particularly chironomids. During the summer, the cove station (Station 5) had more organisms and more species than any other station, and the cause of this is not clear. Sediment organics were quite low at Station 5 and since many of the species were detritivorous/herbivorous chironomids, it seems unlikely that abundant food resources was the cause of the high densities. The cove benthos may for some reason be exposed to lower predation, or some unmeasured physical parameters of the cove may make it a more suitable habitat for many of the macrobenthos. Again, the present data are not adequate to determine causation. The Tugaloo River station (Station 7) differed from all other stations in being dominated by Chaoborus sp. throughout the study. Whether this is a result of physical and chemical environmental parameters, predation differences, or simply a temporary demographic phenomenon is unknown. Station 9 is clearly a highly physically stressed environment, with most organisms being excluded by the high current and shifting sediments. Station 12 on the Savannah River differes from the stations above the dam in that it contains typical riverine species. Allowing for the fact the grab sampler used under-

estimates the abundance of mayflies, caddisflies, stoneflies, and odanates, this station contains a typical river fauna. Despite the fact that the deep-water of the lake is low or devoid of dissolved oxygen at some times of the year, the water is well-oxygenated by the time it reaches Station 12. As an example, in the summer the deep-water at Station 3 was anoxic and at Station 1 contained only 4 mg/l of dissolved oxygen. By the time the water had been released and traveled approximately one kilometer downstream (Station 11), the dissolved oxygen concentration was 8.4 mg/l and in an additional two kilometers (Station 12) had reached 9.7 mg/l. These river water oxygen concentrations are sufficient to support a typical riverine fauna.

The sampling methods and station locations in this study were adequate for determining spatial and seasonal distribution patterns of most macrobenthic taxa in this water system. Somewhat more frequent sampling and more stations would have permitted a refinement of these patterns, but would increase the projects costs concomitantly. However, survey studies such as this are ill-equipped to evaluate the processes which structure the observed communities, rather they take the first step of identifying the community members and documenting patterns of populatic abundances.

F. SEDIMENTS

Physico-chemical characteristics

Grain size analysis results are included in Appendix F-1. In general, grain size was smallest at lake stations nearest the dam and largest in the river stations. Stations 1, 2, 3, 6, and 7 were predominantly silts and clays, with over 50% of the sediment with a diameter of less than 0.250 mm. Stations 4, 5, 8, and 9 are intermediate in size with the majority of the grains between 0.5-0.125 mm in diameter. Stations 11 and 12 are dominated by pebbles with more than 50% of the particles having a diameter in excess of 0.5 mm.

TKN values averaged slightly higher in the fall than in the spring with ranges of 30-1330 mg N/kg and 5-3383 mg N/kg, respectively. River concentrations were 5-10 times lower than the lake stations. TOC and phosphorus values were also higher in the fall than in the spring with ranges of 0.3-16.2 mg C/l and 620-3200 mg P/l, respectively (Appendix F-1).

Oil and Grease values were higher in the fall than in the spring with maximum values of 650 mg/kg in the spring and 800 mg/kg in the fall. There were five measurements above the detection limit in the spring and nine for the fall. Solids, both % total and % volatile, had no discernible trends (Appendix F-1).

Metals

All metal data for Hartwell Lake sediments is presented in Appendix F-2. All concentrations are in mg/kg dry weight unless otherwise noted. The following metals, with maximum levels, were temporally distributed with higher values in the spring; nickel (66.8), zinc (138), copper (33.9), lead (74.7) and manganese (1280). Iron also followed this pattern and values were between 3 and 730 g/kg. The reason for this "seasonality" is unknown. Cadmium (total range of <0.1-70.3) was present at eight of twelve stations in the spring but was not detectable at any station in the fall.

Zinc, copper, iron, and lead were spatially distributed with lower values in the river stations than in the lake stations. Manganese was the reverse and the remaining metals did not show any horizontal variation.

All values were within ranges reported for other southeastern lakes (Lake Murray, S.C., Lake Seminole, Fla.) and comparable values have been previously reported for Hartwell Lake. The reasons for the various distributional patterns of metals in sediments are unknown, but at present, Hartwell Lake does not appear tc have any potential problems associated with metal contamination.

Organics

Endrin and mirex were more prevalent in the fall, with both being undetectable in the spring. Ranges for these two insecticides were <0.2-12 and 1-23.3 ug/kg wet weight. DDT, DDE, and DDD were consistently present

in approximately 10x higher concentrations during the spring. It is not known why this trend occurred as DDT has been banned since 1972 and comparable values for both seasons would be expected. One possible explanation may be the difficulty in assuring that the exact same locations were sampled during the spring as the fall, however the probability of areas of higher concentrations being sampled at all 12 stations during the fall is remote. The possibility of contamination is not likely as blanks and duplicate analyses all gave acceptable results.

DDT, DDE, and DDD all were present in higher levels at stations 4-8, especially in the spring. These are all either upper lake stations or are in coves or arms off of the main lake body. Chlorinated hydrocarbons are known to have an affinity for adsorption onto particles and if these three compounds are entering Hartwell Lake primarily via land runoff, then these near-shore stations would be expected to have greater concentrations than ones located in the central portions of the lake. This would be true as particulates (with adsorbed pesticides) would be sedimented out before reaching the more distant stations. DDT values were less than 400 ug/kg dry weight, with two exceptions. During March, stations 2 and 4 had 1210 and 811 ug/kg, respectively. The maximum DDE value was 182 ug/kg and DDD levels were lower than 169 ug/kg dry weight.

Polychlorinated biphenyls (PCB) were spatially distributed as levels were lower (<1-600 ug/kg) in the river stations (9-12) and in the lower lake stations (1-3). Stations 4-8 normally had values greater than 1000 ug/kg dry weight. Stations 7 and 8 had concentrations greater than 1000 ug/kg during the spring and yet values were less than 1 ug/kg in the fall. As was the case for DDT, it is not known why this distributional pattern occurs. Future investigations into the distribution of PCB in Hartwell Lake should center around the 12 Mile Creek section as this was the site of PCB releases by the Sangamo Corporation during the early 1970's.

Chlordane values were also higher in the spring than in the fall at Stations 4-8, averaging just over 2000 ug/kg dry weight. While chlordane is a common environmental contaminant, it is possible that these relatively high values represent both actual chlordane levels and contributions from interfering gas chromatographic peaks from the high PCB levels found at these stations during the spring.

Toxaphene is one of the most heavily used insecticides in the United States, but was relatively rare in Hartwell Lake sediments. Quantities greater than 100 ug/kg were recorded at Stations 4 and 9 and only during the spring. Station 9, with 265 ug/kg, is a river station with a shallow, sandy bottom with little organic matter. Toxaphene is known to undergo reductive dechlorination in a variety of systems, including anoxic sediments, and the resultant product is difficult to quantify as toxaphene. The presence of toxaphene at Station 9 (with a well oxygenated bottom) and its absence at the lake stations suggests that this chemical alteration may be occurring. Due to the large-scale use of toxaphene, future studies of chlorinated hydrocarbons in sediments should include techniques to identify and quanify this altered form of toxaphene.

In general, chlorinated hydrocarbon concentrations in Hartwell Lake sediments were within the ranges reported in STORET for previous Hartwell Lake and Clark Hill Reservoir sediments. Future investigations into the overall occurrence of these compounds should concentrate, or certainly encompass, the areas of Stations 4-8 of this study as higher concentrations of virtually all organics were recovered from these locations.

G. TISSUES

There was no significant difference in concentrations among the various fish species when all of the metals are considered. Similarly, there was no difference between the mollusk species. For organics, catfish had slightly higher concentrations than did bass or bluegills while there was no comparable trend for the invertebrate species. When comparing metal concentrations in fish to those in clams, clams averaged 10x higher concentrations than did fish, except for mercury where the levels were approximately the same for both groups of organisms. The pesticide concentrations were similar for both the fish and the clams. The above indicates that future studies need only analyze mollusk tissues for both metals and pesticides. It would not seem to matter whether the more abundant Corbicula or the larger Anodonta is used.

Metals

Metal concentrations in fish tissues are presented in Appendix G-1 and in invertebrate tissues in Appendix G-2. Cadmium, Arsenic, and Selenium concentrations were all below the detection limit of 0.1 ug/kg wet weight, while maximum values in clam tissues were 0.32, 0.08, and 0.16, respectively.

There were no station-to-station trends for either clams or fish and the only seasonal trend evident was for lead in clam tissue, where levels were higher in the spring. Values ranged from 0.2-3 ug/kg wet weight in March and 0.2-0.8 ug/kg in October, with one exception. Clams (Anodonta) from Station 9 averaged 65 ug/kg during the spring, a value more than 20x those for all other samples, suggesting possible contamination of this one sample.

Concentrations of mercury were the same for both the invertebrates and the fish with ranges of 0.08-0.7 ug/kg wet weight. Maximum chromium values for fish and clams were 0.84 and 2.69, respectively, while maximum zinc values were 9.16 and 37.82 ug/kg for the same organisms.

Organics

Chlorinated hydrocarbon (CHC) concentrations for fish are given in Appendix G-3 and levels for mollusks are in Appendix G-4. As was the case for metals, there was no spatial trend observed for either fish or mollusks. Mirex, chlordane, and dieldrin were the only CHC's more abundant during one season than the other and this tendency was evident only for fish species.

Mirex and dieldrin were present in significant quantities only during the spring with ranges of <1-86 and 1.1-59 ug/kg wet weight, respectively. Chlordane was present during both seasons but was recovered in concentrations 3-5x higher in the fall. Chlordane ranges were 7-96 ug/kg in the spring and 6-357 ug/kg wet weight in the fall.

The following chlorinated hydrocarbons had no discernible trends (spatial or temporal) for either fish or clams. Aldrin had a range in fish tissue of <1-52 ug/kg wet weight. PCB ranges were <1-679 ug/kg in fish tissue and <1-828 ug/kg wet weight in clams. DDT, DDE, and DDD had maximum fish tissue values of 298, 438, and 118 ug/kg, respectively. The tissues of clams contained DDT, DDE, and DDD maximum concentrations of 24, 58, and 5, respectively. Toxaphene ranged from <1-383 ug/kg in fish and <1-186 ug/kg wet weight in clams. Fish tissues contained maximum values for endrin, heptachlor, and lindane of 42, 14, and 12 ug/kg wet weight, respectively.

CHC contamination is not currently a problem in the species analyzed during this study. Averaged values for CHC's did not exceed state recommended standards for aquatic organisms. Values reported here were comparable to concentrations recorded in STORET for animals from both Hartwell Lake and Clark Hill Reservoir.

VI SUMMARY

Hartwell Lake, a large mesotrophic reservoir located primarily in northwestern South Carolina, was studied intensively during the calendar year 1981. Physical, chemical, and biological measurements were conducted during various seasons in order to assess the general prevailing conditions of the entire Hartwell system.

The southeastern United States experienced a severe and prolonged drought during the summer and fall of 1981, resulting in the Hartwell watershed receiving an annual rainfall of more than twelve inches below normal. This caused the Hartwell Lake water level to drop more than 13.5 feet during the period of June to December. While the lowered lake level prohibited sampling some of the shallow sites in the fall where they had been sampled in the spring, there seemed to be little other direct effect of the drought on biological populations.

Hartwell Lake water quality was generally typical of that recorded from both historical Hartwell values and from other southeastern reservoirs. Changes in many water quality values were governed by the formation of a thermocline in the spring, the gradual lowering of this thermocline through the summer and fall, and the subsequent "overturn" or complete mixing that occurred in the winter. The observed trends for dissolved oxygen and pH were of particular interest. The dissolved oxygen level in the hypolimnion decreases in the summer and fall, reaching essentially zero in many of the deeper areas of the lake. Hartwell Lake may be becoming gradually more acidic. When the pH values of this study are compared to historical measurements, a distinct trend towards a decreasing pH emerges. Given the current interest in acid rain, this is one area that warrants a more detailed investigation.

Phytoplankton and periphyton populations were within normal limits for large mesotrophic to eutrophic lakes. Phytoplankton densities were highest in the spring and lowest in the winter with periphyton densities highest in the summer and fall and lowest in the winter. Phytoplankton densities were generally lowest near the dam and increased with increasing distance away from the dam. Periphyton densities were greatest at the two stations immediately below dams (Hartwell and Keowee) and this was likely due to the release of nutrient-rich waters from the bottoms of the lakes.

Zooplankton data exhibited fewer trends than did any other measured parameter. While there was little variation between duplicates, indicating that the measurements were reliable, there was no obvious pattern of spatial distribution throughout the entire Hartwell Lake system. There were seasonal distribution patterns for zooplankton densities, but only for individual stations. The Hartwell Lake zooplankton population was similar to many other warm-water lakes yet was markedly different from the zooplankton population of Lake Keowee, located just upstream from Hartwell Lake.

Macrobenthic invertebrates, due to the diverse nature of the community, also exhibited few trends that remained consistent over the year and throughout the Hartwell Lake system. In general, worms and mollusks predominated at the deeper lake stations while insect larvae were more common in the stream stations. Seasonal densities were entirely dependent on the species and often varied from station to station. The observed differences were likely the result of life history and/or predation patterns.

Sediment grain size ranged from silts and clays at the lake stations near the dam to pebbles at the river stations. The values of all sediment metal analyses fell within the ranges reported from both earlier Hartwell investigations and from other southeastern lakes. Organics (pesticides and PCB) were also within the ranges reported in STORET for Hartwell Lake and Clark Hill Reservoir sediments.

There was no significant difference in metal concentrations of the tissues of all fish species examined. Both species of clams averaged ten times higher concentrations of metals than did fish. Organic concentrations were similar for both clams and fish, with the catfish having slightly higher concentrations than did the bass or bluegill. Metal and organic contamination of tissues was not a problem in the Hartwell Lake system.

This report provides a comprehensive survey of the existing conditions that occur in Hartwell Lake and its inflowing streams and outlet river. All data generated during this study is stored in EPA's STORET system

VII RECOMMENDATIONS

The following recommendations were synthesized from comments made from experts in a particular field, laboratory personnel, and individuals involved with field collections. They include suggestions for future work that would be of interest to both the scientific community in general and the Corps in particular.

This study was designed to accumulate a large volume of information in a relatively short amount of time and with, as always, a limited budget. In this light the project was a success, sampling a wide variety of habitats and collecting information on a tremendous number of biological and chemical species. In short, a thorough, one-year baseline study on a large aquatic system was performed. With this in mind, a broad recommendation is that future studies concentrate on specific areas of the system, allowing more intensive localized sampling. This, in turn, would allow predictive modelling capabilities, something not possible in the current study.

With the formation of Richard B. Russell Lake imminent, the next project on Hartwell Lake should be a detailed investigation of the areas immediately above and below the dam. Three or four stations (instead of the single Station 1 in the present study) in front of the dam and 5 or 6 stations (instead of 2) below the dam, over a longer stretch of the Savannah River, would enable a better understanding of the potential impact of dam release directly into another reservoir. A more detailed sampling schedule is also recommended, with sampling monthly instead of quarterly. Sampling should include water and sediment chemistry analysis, periphyton and macrobenthic invertebrate surveys, and, in addition, fish population studies within the Savannah River. This sampling regime would result in a better understanding of the impacts that may occur when Hartwell Lake water is emptied directly into another reservoir.

Another area that needs a more intensive sampling effort is the determination of bacterial concentrations within the lake, particularly next to high-use recreational areas. While this study did not find levels that are cause for concern, the limited sampling (four days per year) at each station may not be sufficient when dealing with such ephemeral populations.

Finally, a systematic, thorough, long-term study needs to be initiated to monitor accurately the pH of the Hartwell Lake system. This report suggests that a overall lowering of the pH may be occurring in the system and this seems to pose the greatest immediate threat to Hartwell Lake. The ideal study would establish permanent stations throughout the Jocassee-Keowee-Hartwell-Russell-Clarks Hill system.

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X ABBREVIATIONS

List of Abbreviations

AA	Atomic Absorption Spectrophotometer
AA/AE	Atomic Absorption/Atomic Emission Spectrophotometer
ASTM	American Society of Testing Materials
BOD	Biological Oxygen Demand
^oC	Celsius degrees
CH_2Cl_2	Methylene Chloride
cm	centimeter
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
DO	Dissolved Oxygen
drywt	dry weight
dsf	day-second-feet
EPA	Environmental Protection Agency
^oF	Farenheit degrees
fmsl	feet (above) mean sea level
GC	Gas Chromatograph
GC/MS	Gas Chromatograph/Mass Spectrograph
g	gram
JTU	Jackson Turbidity Units
kg	kilogram
km	kilometer
l	liter
m	meter
ug	microgram
ul	microliter
umHos	microhms
mg	milligram
ml	milliliter
mm	millimeter
mv	millivolt
MPN	Most Probable Number
NBS	National Bureau of Standards
NOAA	National Oceanographic and Atmospheric Administration
ORP	Oxidation-Reduction Potential
PCB	Polychlorinated Biphenyl
pH	Negative log of Hydrogen Ion Concentration
Pt-Co	Platinum-Cobalt
PVC	Polyvinyl Chloride
r^2	Correlation Coefficient
SCUBA	Self-Contained Underwater Breathing Apparatus
stdunits	standard units
STORET	EPA's data STOrage and RETrieval system
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon

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